

Modeling the Lake Eucha Basin Using SWAT 2000

Final Report

Submitted to:
Tulsa Metropolitan Utility Authority

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August 9, 2002

Acknowledgments

We would like to thank Jason Hollenback, and hourly employees at the Delaware County Cooperative Extension Service, and Mike Bryan and Joe Schneider at the Delaware County Conservation District for their assistance with this project. We also thank Megan Perry for her work with the nutrient load estimates.

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Executive Summary

The Lake Eucha/Spavinaw Basin was modeled using Soil and Water Assessment Tool (SWAT) to evaluate the nonpoint source (NPS) nutrient loading to the lakes and its origins. Additional SWAT simulations evaluated the effect of various soil test phosphorus and litter application scenarios on loading to Lake Eucha.

State-of-the-art Geographic Information System (GIS) and weather data were used in the model. Land cover data were developed from satellite imagery and ground truth data specifically for this modeling effort. In addition, high detail daily rainfall estimates were derived from Next Generation Weather Radar (NEXRAD) data and incorporated in the model.

Nutrient loads for the basin were estimated using the US Geologic Survey (USGS) program LOADEST2 using observed water quality measurements, and streamflow estimates provided by both the City of Tulsa (COT) and the USGS. The hydrologic portion of the model was calibrated using three USGS streamflow stations. The phosphorus portion was calibrated using data from eight COT water quality stations.

The calibrated SWAT model estimated the average annual total phosphorus loading to Lake Eucha to be 48,000 kg/yr, which includes 11,400 kg/yr from the City of Decatur point source for the period 8-1-1998 to 3-15-2002. Figure 1 depicts total phosphorus load sources as predicted by the SWAT model. The simulation suggests row crop contributed 49% of the total phosphorus load from only 2.6% of the basin. It is important to note that this row crop estimate assumes uniform crop and tillage practices across the basin, the same soil test phosphorus (STP) in row crop and pasture, and unverified erosion and phosphorus parameters. Pastures accounted for about 21% of the total P load, but accounted for 42% of the soluble P load.

The SWAT model was also used to quantify the source of the phosphorus load. Figure 2 provides the total phosphorus load by source or activity. The fraction due to poultry litter was shown to be less than half that due to STP. Thus, if litter application were halted, total phosphorus load would be reduced immediately by approximately 15%. It should be noted, however, that the application of poultry litter over the past 40 years is ultimately responsible for the current STP levels.

Models are simplifications of the real world, and thus it should be stated that these results contain uncertainty. We have attempted to quantify the portion of that uncertainty due to variations in rainfall, but there are other kinds of uncertainty that cannot be quantified with the current generation of watershed models. Row crop fields in the basin should be soil tested to verify current STP levels as these areas contribute a vastly disproportionate amount of the phosphorus load. Our model results indicate that the application of poultry litter to row crop in the short term has little relative effect, as these areas are likely tilled, incorporating the poultry litter into the soil profile. The model indicates that STP dominates the loading from these areas, which makes our assumption the pasture and row crop STP being the same in a subbasin more critical.

Total Phosphorus Load Allocation by Land Cover to Lake Eucha/Spavinaw

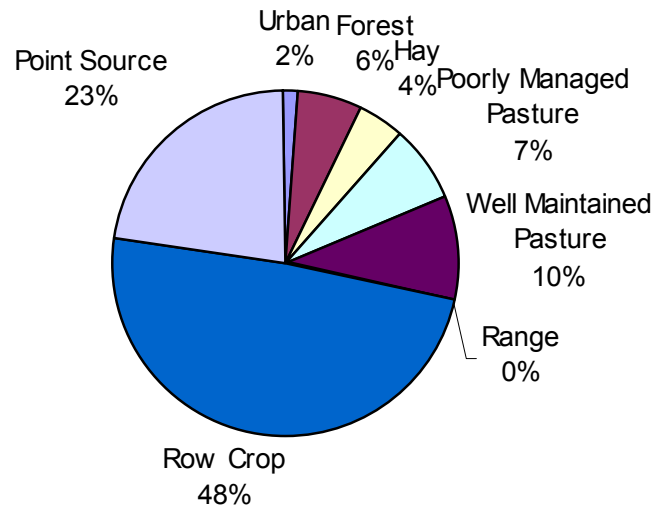


Figure 1 Total phosphorus load allocation by land cover. Derived from SWAT model predictions for the period 1/1998 to 12/2001 and point source data from the US Environmental Protection Agency Permit Compliance System for the period 1/1998 to 3/2002.

Total Phosphorus Allocation by Source to Lake Eucha/Spavinaw

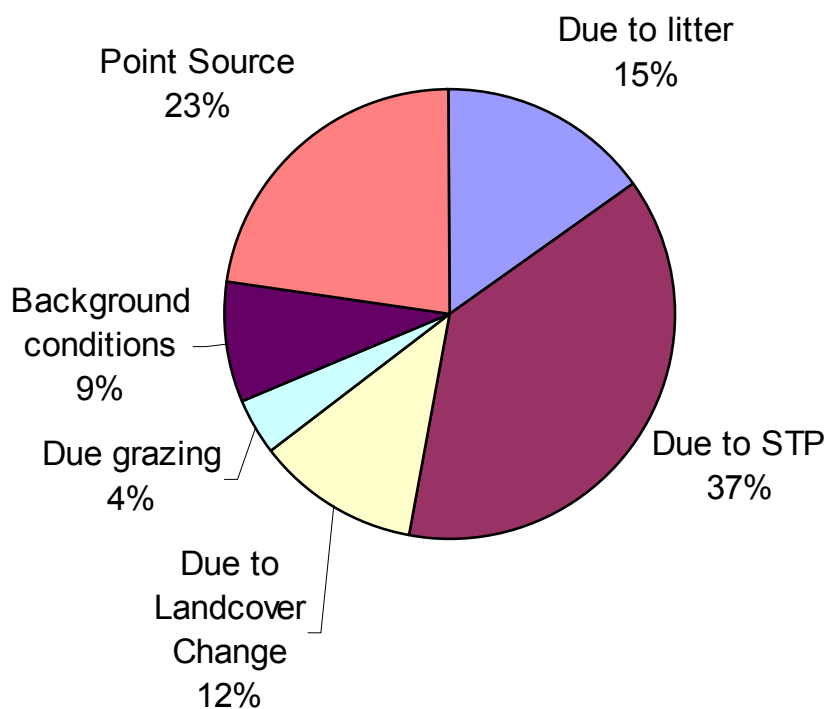


Figure 2 Total phosphorus load allocation by source or activity. Derived from SWAT model predictions for the period 1/1998 to 12/2001 and point source data from the US Environmental Protection Agency Permit Compliance System for the period 1/1998 to 3/2002.

Introduction

Lakes Eucha and Spavinaw water quality is being degraded from excess algal growth. This excess growth is the result of an overabundance of nutrients in the lake, assumed to be primarily phosphorus. Phosphorus may enter the water column from lake sediments below (internal load) or arrive with stream flow (external load). Essentially all the phosphorus in the lakes originate from the watershed, since current lake sediments arrived from stream flow too. However, for the purposes of our analysis we will consider these sources separate and will study external sources only.

External loads originate from either point sources, such as the City of Decatur municipal waste water treatment plant, or from nonpoint sources like pastures. The majority of the phosphorus loading has been attributed to nonpoint sources (Wagner and Woodruff, 1997; Storm et al., 2001). Fields in the Lake Eucha basin have received phosphorus from poultry litter application for many years. Poultry litter is often applied to meet the crop's nitrogen requirements. When phosphorus in excess of what the crop can use is applied, phosphorus builds up in the soil. Runoff extracts soluble phosphorus from the soil and litter, and carries sediments containing phosphorus to the lakes.

The SWAT (Soil and Water Assessment Tool) model was used to predict how external loads are affected by management changes, and where the loading originates. A range of soil test phosphorus levels and litter export scenarios were simulated.

SWAT Input Data

GIS data for topography, soils, land cover, and streams were used in the SWAT model. These data used were the most current at the time of compilation. Observed daily rainfall and temperature data were used in all modeling.

An ArcView GIS interface is available to generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. GIS data layers of elevation, soils, and land use are used to generate the input files. Observed temperature and precipitation can be incorporated. If no observed weather data are available, weather can be stochastically simulated.

Topography

Topography was defined by a Digital Elevation Model (DEM). DEMs for the United States are available for downloading via the Internet. The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of subbasins. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Individual 1:24,000 thirty meter DEMs were stitched together to construct a DEM for the entire basin. When tiled, 1:24,000 DEMs often have missing data at the seams. These missing data must be replaced. A 3x3 convolution filter was applied to the DEM to produce a seamless filtered DEM. Any missing data at the seams of the original DEM were replaced with data from the filtered DEM. The resulting seamless DEM retains as much non-filtered data as possible (Figure 3). Filtering tends to remove both peaks and valleys from a DEM thereby reducing the perceived slope. For this reason the use of filtered data were kept to a minimum.

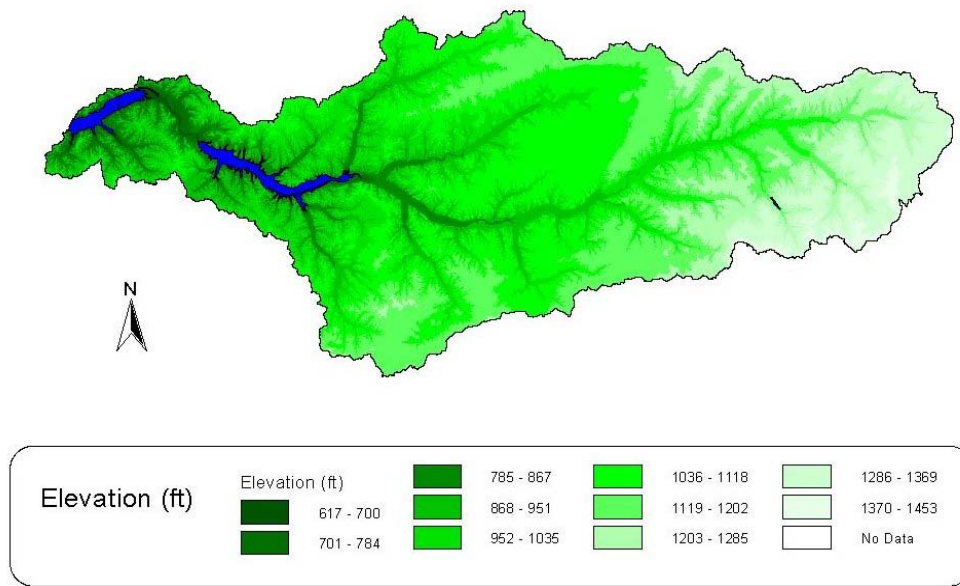


Figure 3 Seamless Digital Elevation Model (DEM) for the Lake Eucha/Spavinaw Basin constructed from U.S. Geographic Survey 1:24,000 DEMs.

Soils

Soil GIS data are required by SWAT to define soil characteristics. SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes for any given soil. The GIS data must contain the S5ID (Soils5id number for USDA soil series), or STMUID (State STATSGO polygon number) to link an area to the STATSGO database.

The soils layer was derived from two separate GIS coverages (Figure 4). The Oklahoma portion is 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma Natural Resource Conservation Service (NRCS). The Arkansas portion is a 1:20,000 order II soil survey digitized by the University of Arkansas. The soils database used by SWAT indicated that the hydrologic soil group for several silt and gravelly loams were in the C and D classes. We modified these to B and C classes, respectively, to reflect local conditions (Table 1).

Table 1 Hydrologic soil group modifications used in the SWAT model for the Lake Eucha/Spavinaw Basin.

Soil Name	S5ID	Old Hydrologic Soil Group	New Hydrologic Soil Group	TEXTURE
CAPTINA	AR0001	C	B	Silt Loam
TONTI	AR0037	C	B	Gravelly Silt Loam
TONTI	AR0120	C	B	Gravelly Silt Loam
CARYTOWN	MO0072	D	B	Silt Loam
PARSONS	OK0011	C	B	Silt Loam
TALOKA	OK0016	D	C	Silt Loam
STIGLER	OK0040	D	C	Silt Loam

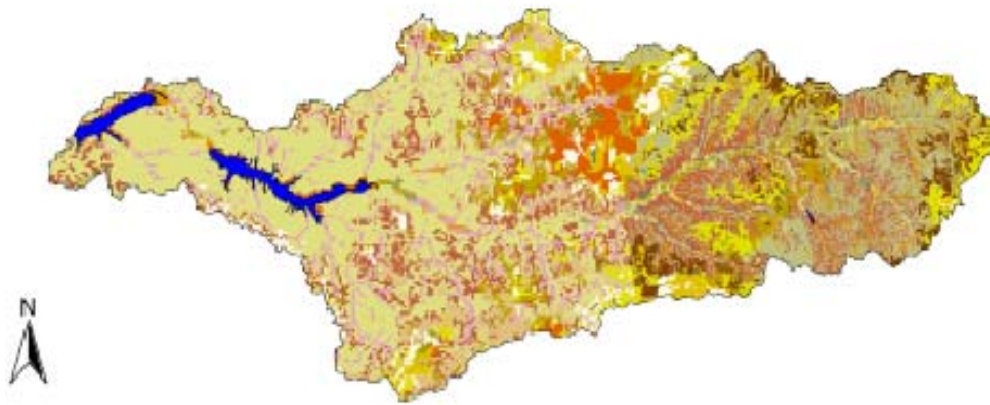


Figure 4 Soil distribution in the Lake Eucha/Spavinaw basin.

Land Cover

Land cover is perhaps the most important GIS data used in the model. The land cover theme affects the amount and distribution of pasture, row crop, and forest in the basin. These land covers are radically different. Forested areas contribute little to the nutrient loading, while pastures and row crops are thought to be the primary source of nutrients entering the lakes. Row crop in this basin is assumed to be green beans followed by winter wheat, based on the observations of Delaware County Cooperative Extension agent Jason Hallenbeck.

It is important that land cover data be based on the most current data available, since land cover changes over time. Land cover was derived from 30 meter Landsat 7 ETM+ imagery, digital aerial photos, and 45 ground truth data points provided by Oklahoma State University (OSU) (Figure 6). Imagery for June 12, 2001 was obtained and classified by Applied Analysis Inc. (AAI). An unsupervised iterative self-organizing data analysis (ISODATA) clustering algorithm was applied by AAI to define spectral categories. After several iterations these categories combined into individual land covers. The report of the AAI classification is located in Appendix B. Table 2 contains the fraction of the basin covered by each category as determined by AAI and as interpreted by SWAT.

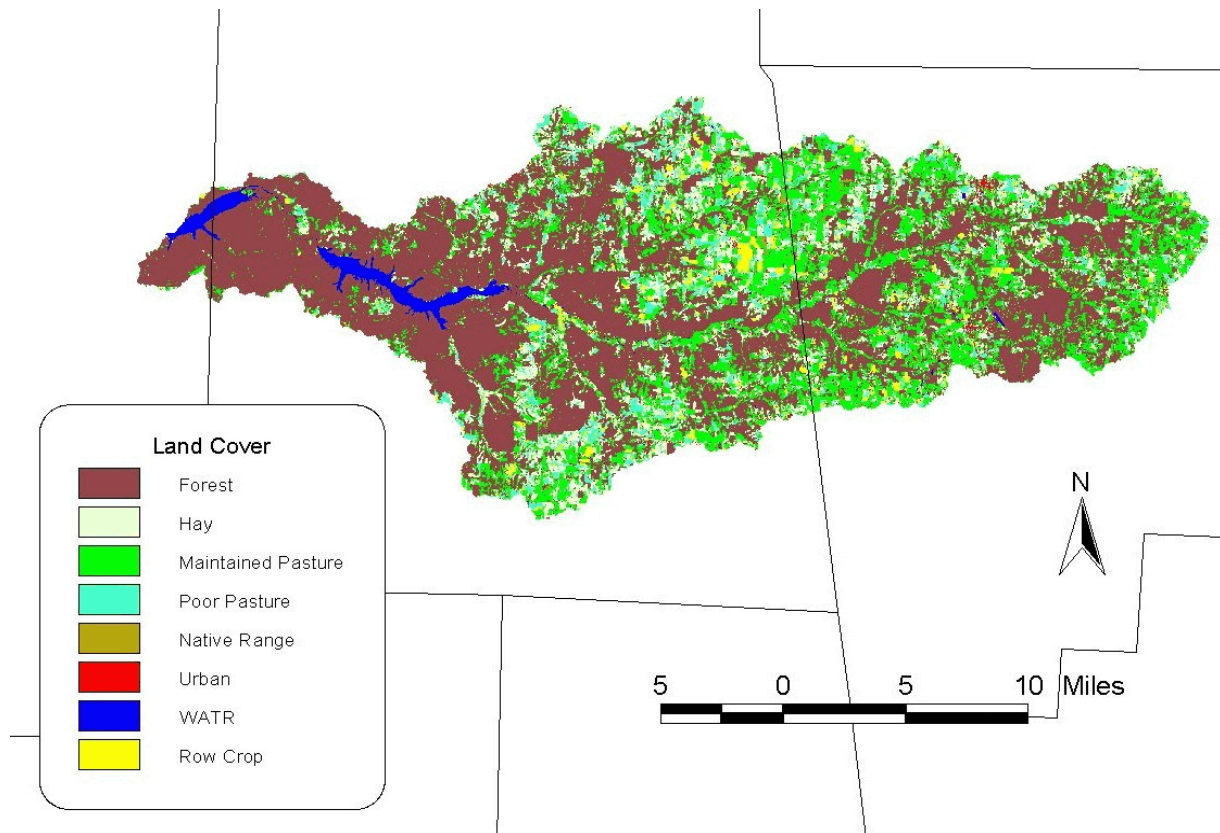


Figure 5 Landsat Thematic Mapper derived land cover for the Lake Eucha/Spavinaw basin.
Source: Applied Analysis Inc.

Table 2 Land cover fractions from the original land cover data and as interpreted by the SWAT model.

Land Cover	SWAT	Original
Forest	51.3%	50.9%
Hayed Pastures	13.3%	13.2%
Well Managed Pastures	23.1%	23.0%
Poorly Managed Pastures	6.5%	6.5%
Brushy Rangeland	0.1%	0.3%
Urban	1.3%	1.5%
Water	1.7%	1.9%
Row Crop	2.6%	2.7%

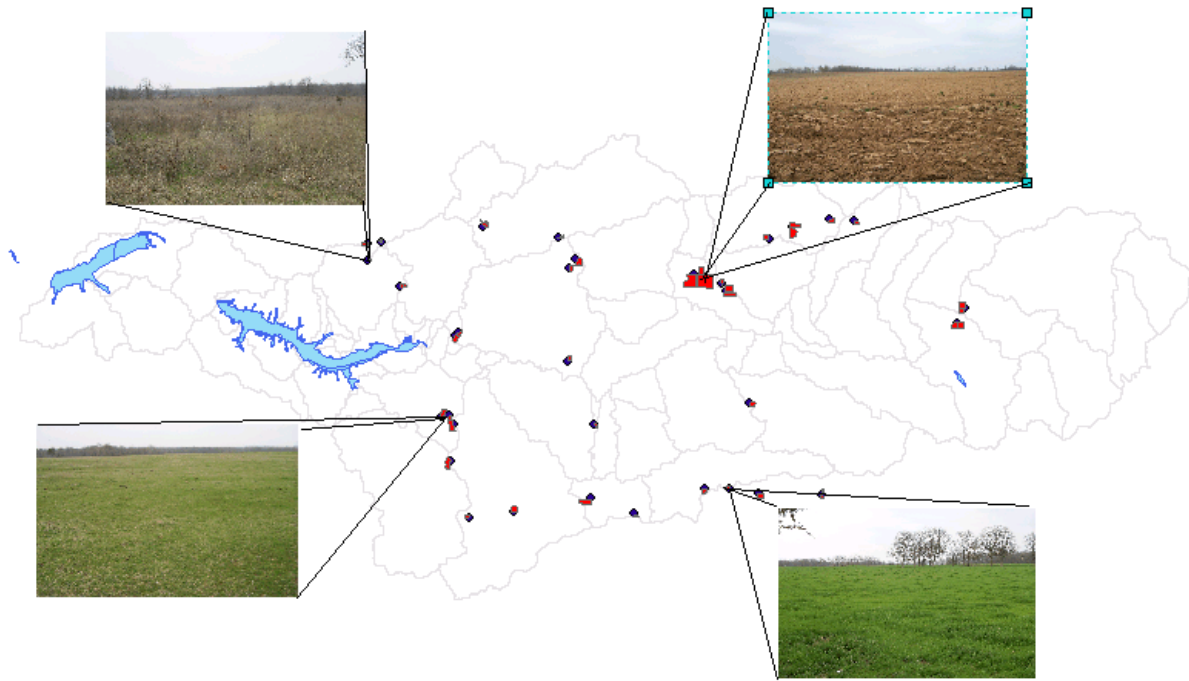


Figure 6 Ground truth locations and selected images provided to Applied Analysis Incorporated by Oklahoma State University. Starting upper right and progressing clockwise, the land covers depicted are range, row crop, well managed pasture, and hay.

Geology

Geology, while not a direct model input, is still useful to determine which areas have similar ground water characteristics. These data, among others, are used to help determine which calibration are used for ungaged areas (Figure 7).

Weather

SWAT can use observed weather data or simulate it using a database of weather statistics from stations across the United States. Observed daily precipitation and minimum and maximum temperature were used in the Lake Eucha/Spavinaw model. A combination of Next Generation Weather Radar (NEXRAD) radar derived precipitation and Cooperative Observation network gage data were used in the SWAT model for the Lake Eucha/Spavinaw basin. The inclusion of these data is usually limited to only cutting edge research in hydrologic modeling.

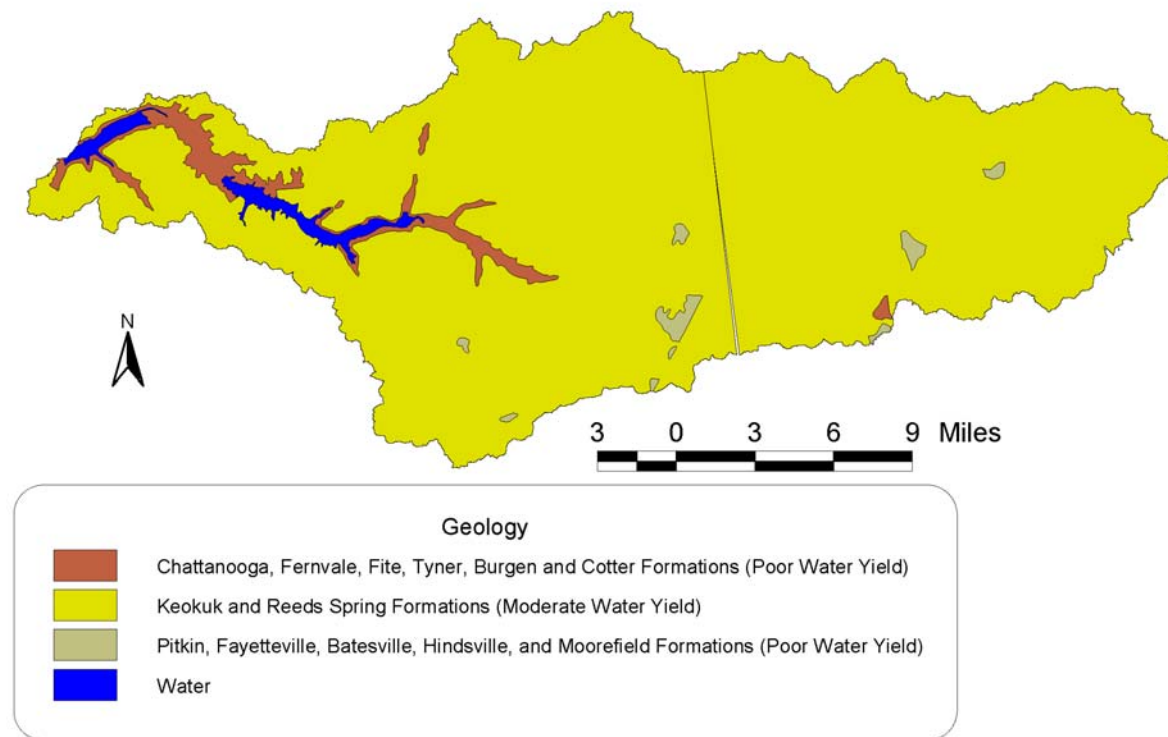


Figure 7 Geology of the Lake Eucha/Spavinaw Basin. Derived from US Geographic Survey and Arkansas Archaeological Survey data.

Radar Derived Rainfall

NEXRAD Weather Surveillance Radar 88D (WSR-88D) derived precipitation estimates were incorporated into the SWAT model. WSR-88D Precipitation data were gage biased and archived by the Arkansas-Red Basin River Forecast Center (ABRFC). These data have a resolution of 4 km and are available from the ABRFC website in Network Common Data Form (NetCDF) format. These data are available in 1 hour, 6 hour, and 24 hour increments. SWAT requires daily rainfall, however the 24 hour increment data from the ABRFC runs from 6 am to 6 am Central Standard Time (CST). Daily data (12 am -12 am CST) were summarized from the 6 hour increment data for use in SWAT. Daylight-saving time was ignored to simplify these calculations.

A significant amount of conversion is required to use the NEXRAD weather data in SWAT. NetCDF format is most commonly used on a UNIX platform and thus PC compatible tools are scarce. A PC compatible text translator ncdumps.exe was written by the NOAAs Geophysical Fluid Dynamics Laboratory. This translator was called from a batch file to convert 6 hour increment NetCDF files to American Standard Code for Information Interchange (ASCII) text. A set of custom programs written in Microsoft Visual Basic were used to view and extract data covering the basin. Figure 8 contains a graphical representation of one 6 hour NEXRAD cumulative precipitation grid. The 1994 to 2002 precipitation estimates used in SWAT were derived from over 10,000 such grids.

Cooperative Observation Network

National Weather Service COOP (Cooperative Observing Network) station data from 27 stations from 1/1/1950 to 3/31/02 were used to supplement the NEXRAD weather data (Figure 9). COOP data are available from the NOAA (National Oceanic and Atmospheric Administration).

COOP data are seldom continuous for long periods of time. Missing days and even months are common. The period of record at stations are inconsistent, so the number of active stations changes with time. When SWAT detects missing data at a station, it generates simulated weather. Therefore, gaps in a station's record were filled using interpolated data from surrounding stations. Shepherd's weighted interpolation was used, because it is computationally efficient. Shepherd's method uses weighting factors derived from the distance to nearby stations within a fixed radius:

$$Z_0 = \frac{\sum_{i=1}^n Z_i W_i}{\sum_{i=1}^n W_i}$$

where Z_0 is the precipitation at the station of interest in mm, Z_i is the precipitation at station i in mm, and W_i is the weighting factor at station i .

Weighting factors are calculated using the distance between stations:

$W_i = (1 - \frac{d_i}{R})^2$ for $\frac{d_i}{R} < 1$ And $W_i = 0$ for $\frac{d_i}{R} \geq 1$
where R is the radius of influence in meters, and d_i is the distance from station of interest to station i in meters.

Due to the inclusion of NEXRAD data, temperature and precipitation processing methods were different. Temperature was only interpolated to patch the period of record at existing stations. Because SWAT requires a fixed network of weather stations, precipitation data were interpolated to the same grid as NEXRAD data (Figure 10). This grid interpolated precipitation data were prepared for the period 1/1/1950 to 3/31/02. These interpolated data were used exclusively before 1994 and used to patch holes in the subsequent NEXRAD data. Because of the large amount of data associated with these weather files, all processing and formatting was done using custom programs written in VBA (Visual Basic for Applications) and Microsoft Excel.

Comparisons were made between the SWAT model (uncalibrated) using COOP and NEXRAD precipitation data. The purpose was twofold, to ensure the model would run properly with NEXRAD data, and to examine how the inclusion of these higher resolution data would effect the model. Figure 11 illustrates how the model using NEXRAD data predicts streamflow compared with standard COOP data.

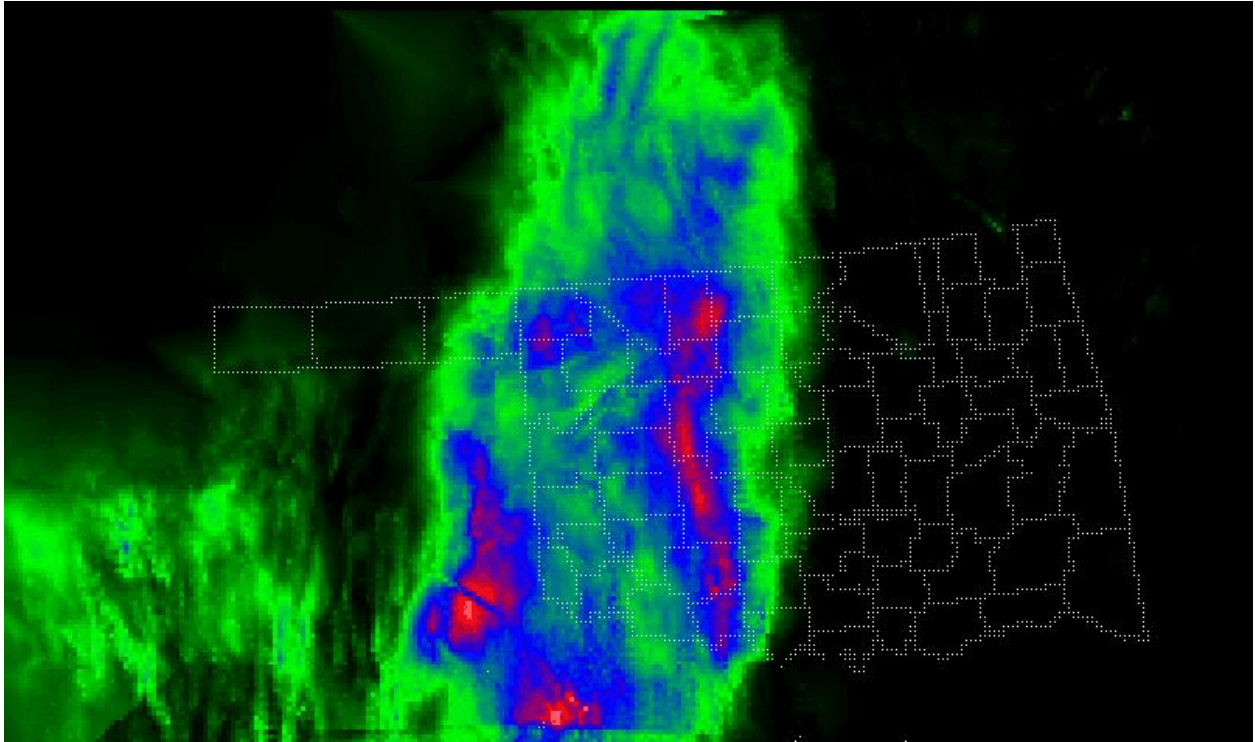


Figure 8 Example four kilometer resolution Next Generation Radar (NEXRAD) precipitation data for the State of Oklahoma, gage biased and archived by the Arkansas-Red Basin River Forecast Center (ABRFC).

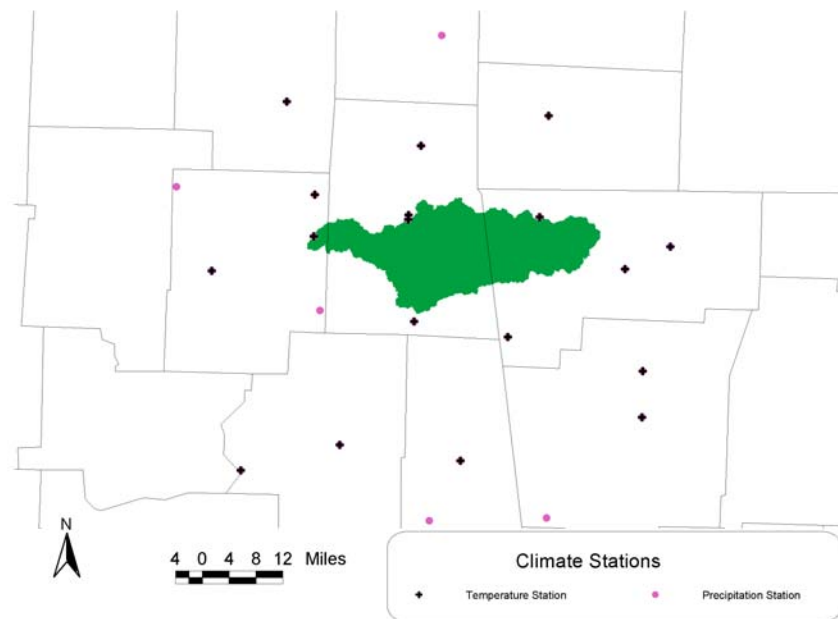


Figure 9 National Weather Service Cooperative Observation (COOP) network precipitation and temperature station locations near the Lake Eucha/Spavinaw Basin.

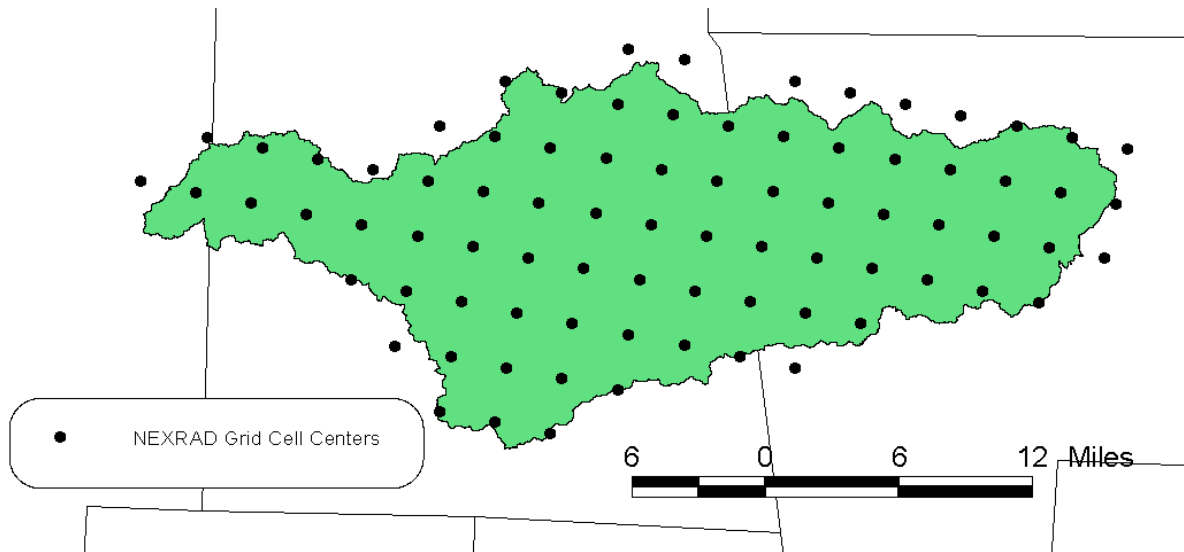


Figure 10 Four kilometer resolution Next Generation Radar (NEXRAD) grid cell centers used to define weather stations in the SWAT model for the Lake Eucha/Spavinaw Basin.

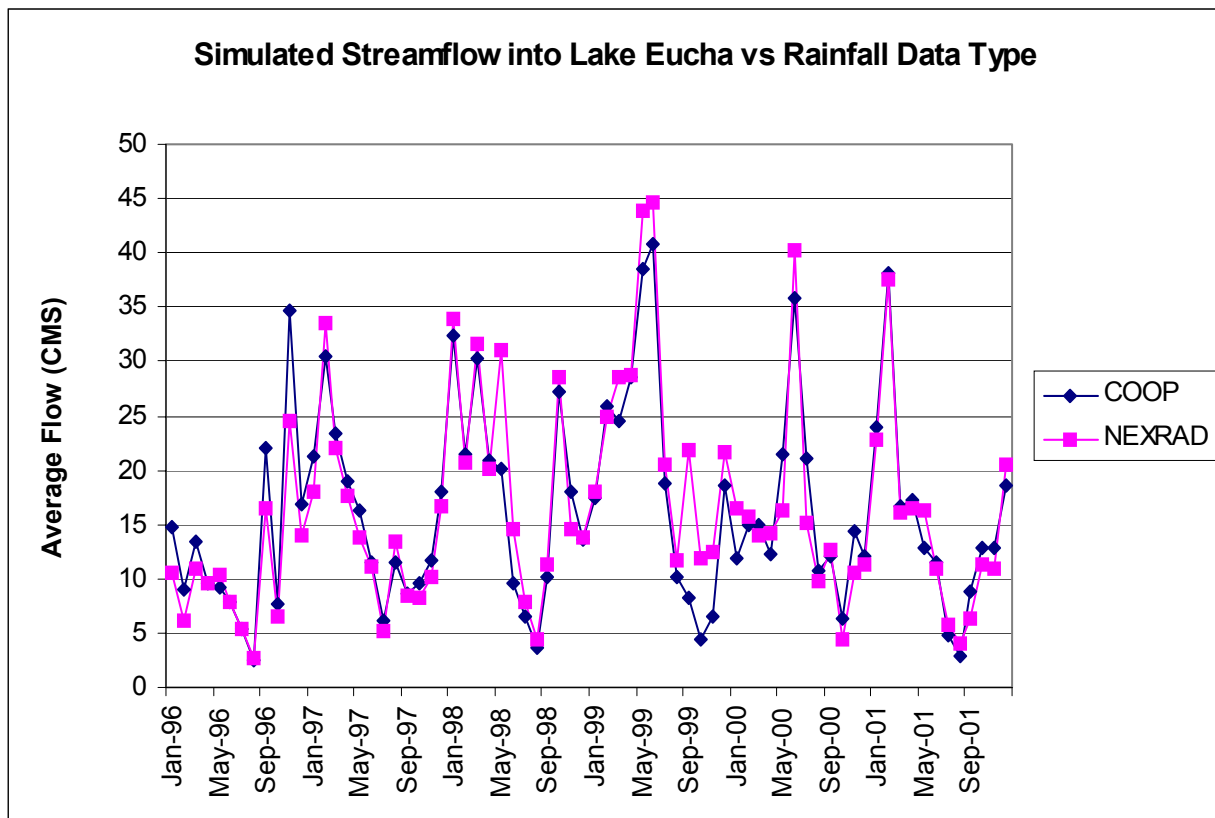


Figure 11 SWAT model (uncalibrated) simulated flow to Lake Eucha for both Next Generation Weather Radar (NEXRAD) radar derived precipitation and Cooperative Observation network (COOP) gage data for the period 1996 though 2001.

Subbasin Delineation

The subbasin layout was defined by SWAT using the DEM, a stream burn-in theme, and a table of additional outlets. The stream burn-in theme consists of digitized streams. Its purpose is to help SWAT define stream locations correctly in flat topography. A modified reach3 file from the US Environmental Protection Agency's BASINS (Better Assessment Science Integrating Point and Non-point Sources) model was used. The theme was modified to remove the outline of both lakes, which the model confused with a stream path. Model predictions are only available at subbasin outlets, so additional outlets were added at points of interest such as gage stations, water quality stations, or lake boundaries. A stream threshold value of 1000 ha was used to delineate subbasins. Threshold area is the minimum contributing upland area required to define a single stream. The result is 68 subbasins (Figure 12). Fewer subbasins would simplify the modeling process, but this level of detail was needed to adequately represent the basin.

HRU Distribution

Each of the 68 subbasins was split into HRUs (Hydraulic Response Units) by SWAT. The *land use [%] over subbasin area threshold* was changed from the default 20% to 1%. This threshold determines the minimum percentage of any land cover in a subbasin that will become an HRU. The *soil class [%] over subbasin area* was also reduced from its default value of 20% to 10%. By reducing these thresholds, the number of HRUs was increased to 1052, approximately three times the number used in the previous modeling study (Storm et al., 2001).

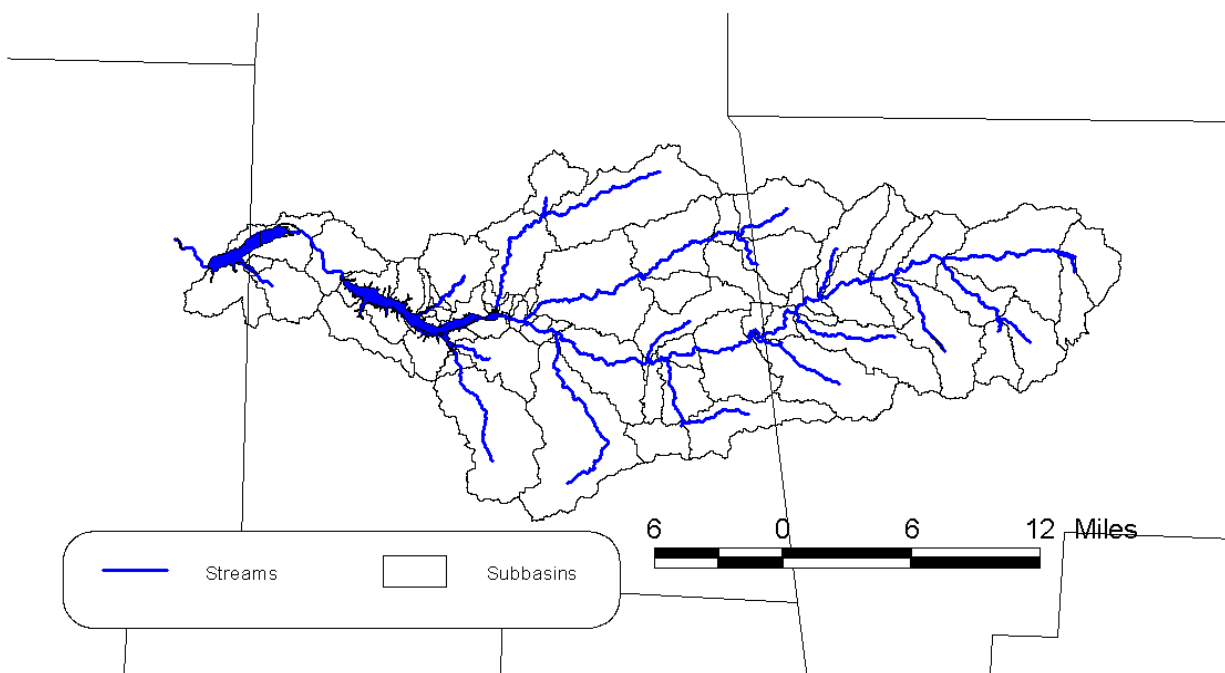


Figure 12 The Lake Eucha/Spavinaw basin divided into 68 subbasins. This configuration was used in all SWAT model predictions unless otherwise noted.

HRU Slope

One weakness of the SWAT 2000 Arcview Interface is that slope is considered uniform for all HRUs in a given subbasin. Forest and pasture HRUs are modeled using the same slope, when in reality they may be radically different. To eliminate this weakness, slopes were estimated from the DEM for each land cover in each subbasin manually. Forested areas (Figure 13) in the basin had an averaged slope of 14.7 % while pasture (Figure 14) and row crop (Figure 15) averaged 5.2 and 3.8%, respectively.

Ponds

Ponds affect the hydrology by impounding water and trapping nutrients. Water in ponds is subject to evaporation and seepage into the shallow aquifer. Nutrients and sediment settle out and are trapped. Test runs using the SWAT model indicate ponds significantly reduced nutrient and sediment concentrations.

Because of the difficulty associated with counting ponds in each subbasin, ponds were assumed uniformly distributed in agricultural portions of the basin. Heavily forested areas were assumed to have no ponds (Figure 16). All ponds in a single Beaty Creek subbasin were counted and summarized. These ponds were defined from 1:24,000 USGS DRG (Digital Raster Graphic). This level of detail was required to define the majority of ponds. These estimates were applied to all subbasins considered to have ponds. Other subbasins with similar land cover appeared visually similar, indicating that ponds are somewhat uniformly distributed throughout pasture areas in the basin. Of the total area in each subbasin, 20% was routed through ponds. Total surface area of all ponds in a subbasin was estimated as 0.32% of the total area of that subbasin. Each pond was assumed to have an average depth of 1.5 meters.

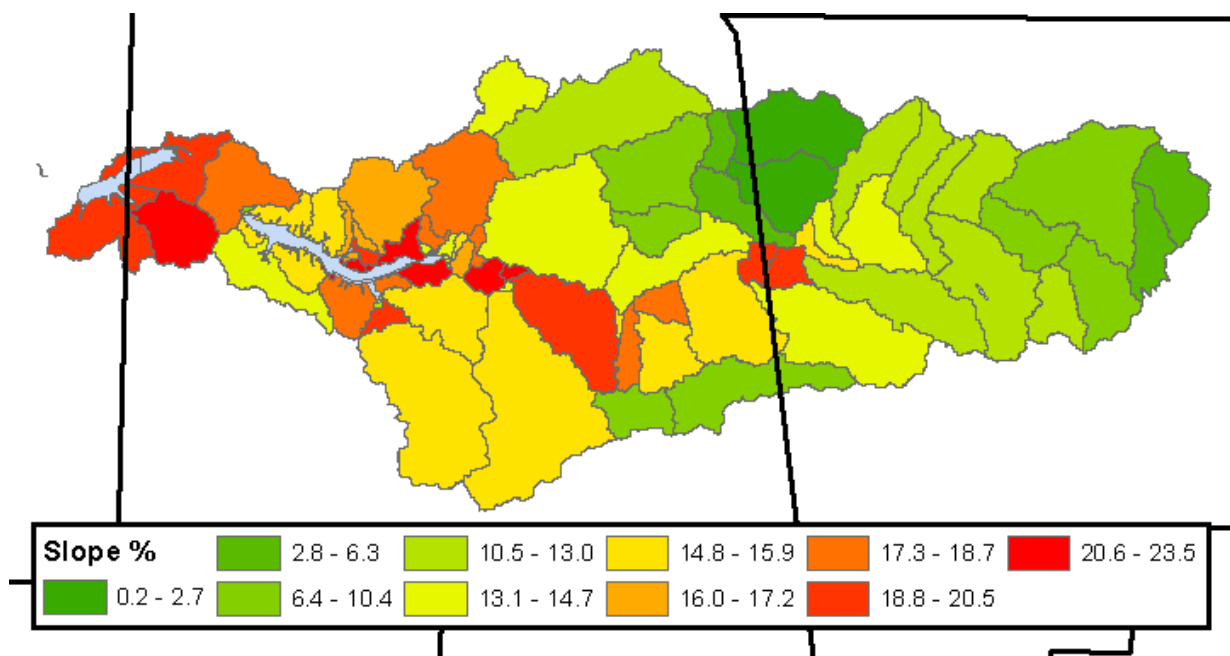


Figure 13 Forest HRU slope by subbasin. Derived from land cover and 30 m Digital Elevation Model (DEM).

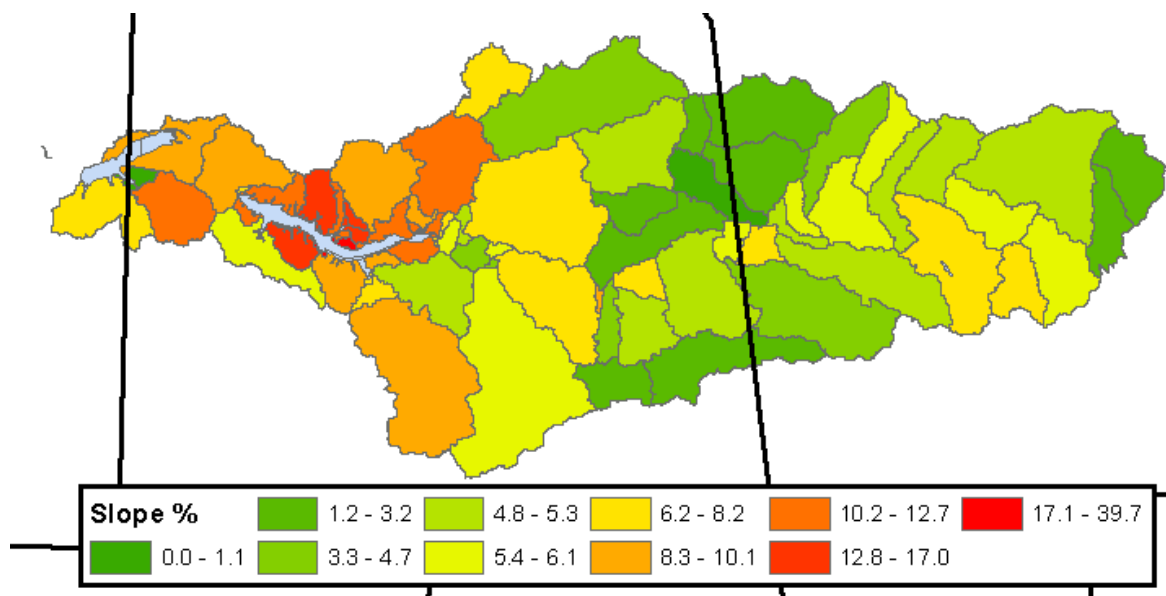


Figure 14 Pasture HRU slope by subbasin. Derived from land cover and 30 m Digital Elevation Model (DEM).

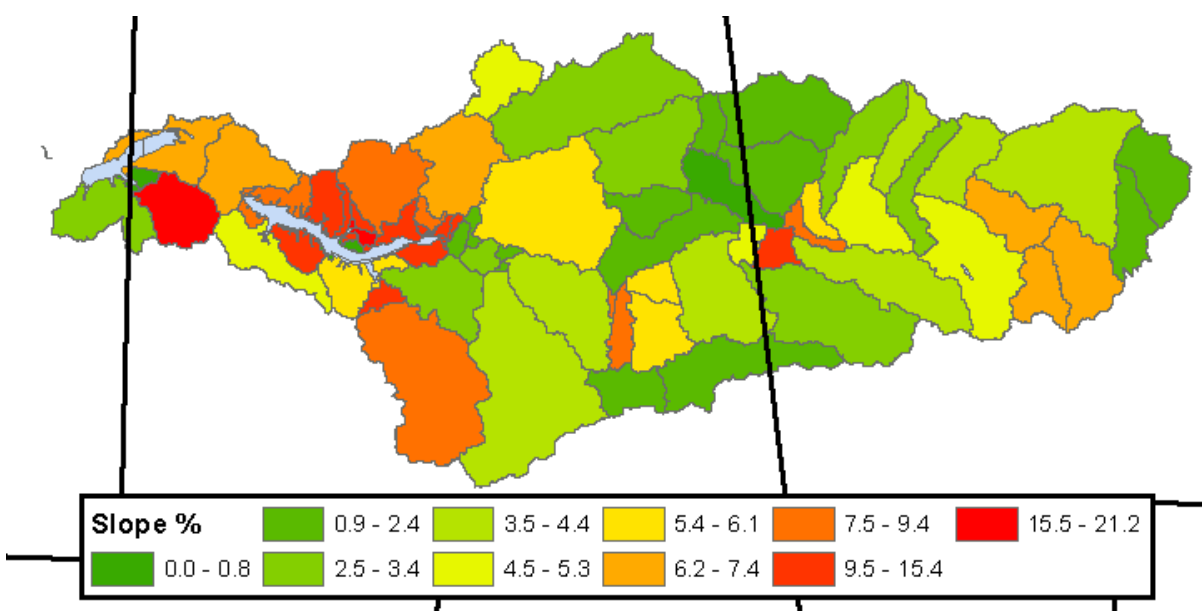


Figure 15 Row crop and Urban HRU slope by subbasin. Derived from land cover and 30 m Digital Elevation Model (DEM).

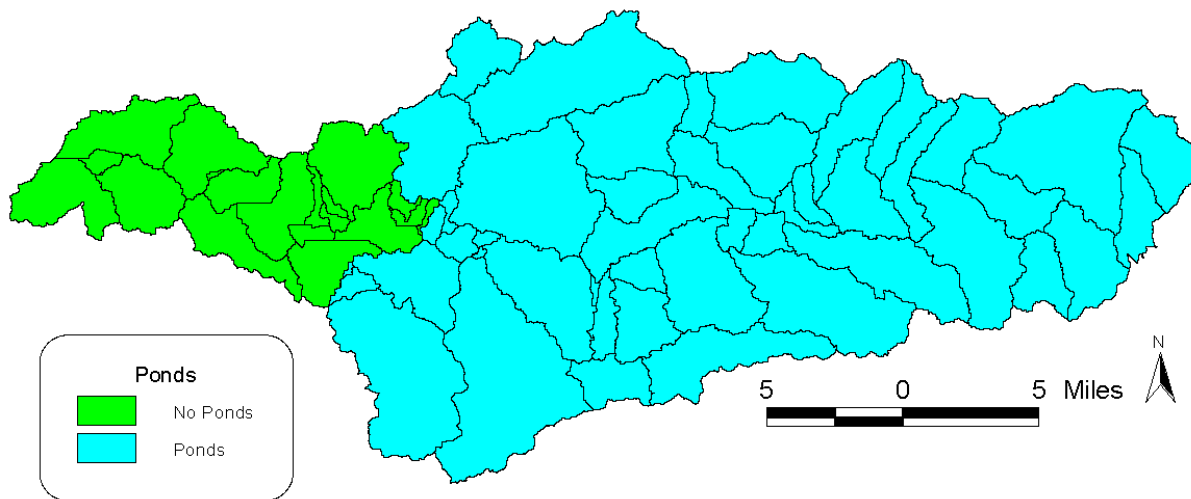


Figure 16 Subbasins in the Lake Eucha/Spavinaw basin assumed to have a significant number of ponds.

Management

SWAT defines management as a series of individual operations. The timing of these operations may be defined by a date, or as a fraction of the total heat units required by the crop. Each land cover is assigned a set of management operations. Following is a list of land covers and their relative coverage of the watershed as depicted in the SWAT Model:

• Forest	51.3%
• Hayed Pastures	13.3%
• Well Managed Pastures	23.1%
• Over-grazed or Poorly Managed Pastures	6.5%
• Brushy Rangeland	0.1%
• Urban	1.3%
• Water	1.7%
• Row Crop	2.6%

Heat Units

Heat unit scheduling is the default. Heat units are accumulated when the average daily temperature exceeds the base temperature of the crop. The base temperature is the minimum temperature required by the plant to grow. The amount of heat units accumulated each day is equal to the average daily temperature minus the base temperature of the plant. When no plants are growing the model uses a base temperature of 0° C and keeps a separate running total. This base 0°C running total is used to schedule planting dates because no heat units can be accumulated until plant growth begins.

Temporal Stability

Past modeling efforts have encountered difficulty with changing characteristics of land cover types that should be relatively stable. A low detail model of the Lake Eucha Basin was created and run for a 50 year period to evaluate the temporal stability of each set of management operations (Figure 17). A harvest operation was included for forest to increase stability. The harvest operation was modified such that no nutrients were removed with harvested material.

Litter

Litter application rate was varied by land cover within each subbasin. Hay pasture received the base litter application rate. Poorly managed pastures received 70% of the base rate, while well managed pastures receive 130% of the base rate. Row crop received litter to supplement commercial fertilizer nitrogen application rates to recommended levels.

Pasture management is not uniform across the basin. The amount of litter applied in each subbasin is different. The SWAT interface was not used to generate these management files (.mgt), because that required each file to be manually modified. There is one management file for each of the 1052 HRUs. With multiple management changes, the task would be daunting. Therefore, a program was written to create files identical in format to those generated by the ArcView SWAT interface.

Cattle Stocking Rate

To verify the stocking rate used for pastures in the SWAT model, we estimated the actual number of cattle in the basin. County level National Agricultural Statistics Service (NASS) cattle estimates for the period 1998-2001 were combined with land cover data to estimate the number of cattle within the basin. We assumed that cattle are evenly distributed across all pastures in Delaware and Benton counties. From these data we estimate the number of cattle and calves in the basin to be 39,000 head.

The SWAT model does not simulate individual cattle. Instead a daily biomass removal and manure application are used to represent the presence of a grazing cow. The amount a cow will consume depends on the type and growth stage of the cow in question. Because there are many different types of cattle in the basin, we use the animal unit concept. Stocking rates are often expressed as animal units. One animal unit could be expressed as a cow and calf pair or two-400 lb stockers; both would consume a similar amount of grass. The total number of animal units simulated on pastures in the model is 24,500. Wheat is not included in this estimate because it is winter and spring grazing only, and thus this is a conservative estimate. Since the NASS derived estimate is the number of cattle and calves, these estimates are not directly comparable without assuming a specific type of animal (Table 3). The assumption of a 600 lb stocker cattle yields 35,000 head used in the SWAT model and a 10% error in the number of cattle simulated in the basin.

Row Crop

Row crop areas were managed as a winter wheat/green bean rotation. Grazing is suspended when dry biomass falls below 600 kg/ha (approximately 5 inch standing forage; OSU Extension Publication F-2586). Below are the row crop operations and dates used in the SWAT model.

<u>Operation</u>	<u>Date</u>
Grazing ½ Animal Unit/Acre	2/15
Litter Application	3/1
Harvest/Kill Wheat	5/1
Spring Plowing	5/4
Plant Green Bean	5/15
Harvest/Kill Green Bean	8/1
Commercial Fertilizer Application	8/5
Fall Plowing	8/10
Plant Wheat	9/1
Grazing 1/3 Animal Unit/Acre	11/1

Grazing on winter wheat was simulated at a stocking rate of 0.33 animal units per acre (Kansas State University Research and Extension Forage Facts Grazing Wheat Pasture), with 9.35 kg of dry biomass consumed and 3.0 kg of dry manure deposited per hectare (ASAE D384.1). Any time there is less than 1600 kg for well managed pastures and 600 kg/ha for poorly managed or over grazed pastures (dry weight) of biomass per hectare grazing is suspended.

Forest

Only minor modifications to the default management for forested areas were made. Ideal forest management would have contained no harvest operation. However, this operation was required to increase temporal stability.

<u>Operation</u>	<u>Heat Units</u>
Plant	0
Harvest	1.2

Hayed Pastures

A cool season grass was selected as the cover for hay pastures in the model. No grazing was simulated on hay pastures. Hay pastures receive the base litter application rate. The operations are listed below:

<u>Operation</u>	<u>Date</u>
Plant	1/1
Apply Litter	2/1
Cut Hay	4/1
Cut Hay	6/1
Cut Hay	8/1

Well Managed Pastures

Well managed pastures are simulated as lush pastures in good condition. Fertilization rate are increase to 130% of the base litter application rate, and curve numbers are reduced accordingly. Grazing is suspended when dry biomass falls below 1600 kg/ha (4-5 inches of dense cool season grass, Iowa State University Extension, *Estimating Available Pasture Forage*). Stocking rate is simulated at 1/3 AU/acre for 300 days.

Operation	Date
Plant	1/1
Apply Litter	2/1
Graze	3/1

Over-grazed or Poorly Managed Pastures

Poorly managed pastures are simulated as under fertilized pastures in poor condition. Fertilization rates are decreased to 70% of the base litter application rate, and curve numbers are increased. Grazing is suspended when dry biomass falls below 300 kg/ha (1 inch of fair condition cool season grass (Iowa State University Extension, *Estimating Available Pasture Forage*). Stocking rate is identical to that of well managed pastures.

Operation	Date
Plant	1/1
Apply Litter	2/1
Graze	3/1

Brushy Rangeland

Like forests, only minor modifications to the default management for rangeland were made. Rangeland was the most temporally unstable land cover simulated. The addition of a harvest operation increased the temporal stability, but as this cover represents only 0.1% of the basin further modification was deemed unnecessary.

Operation	Heat Units
Plant	0
Harvest	1.2

Urban

Urban parameters are not defined by the management. Management defines cover for pervious areas.

Operation	Date
Plant	1/1

Table 3 Estimates of the number of cattle in the basin derived from National Agricultural Statistics Service (NASS) and those used in the SWAT Model (pasture grazing only) assuming different types of animals.

Used in SWAT (Animal Units)	Type of animal	Animal Units Per Animal	Equivalent Animals in SWAT	NASS Estimate (Animals)	Difference
24,500	Adult Cow	1	24,500	39,000	-37%
24,500	600 lb stocker	0.7	35,000	39,000	-10%
24,500	Cow calf pair	1	49,000	39,000	26%
24,500	300 lb stocker	0.4	61,250	39,000	57%

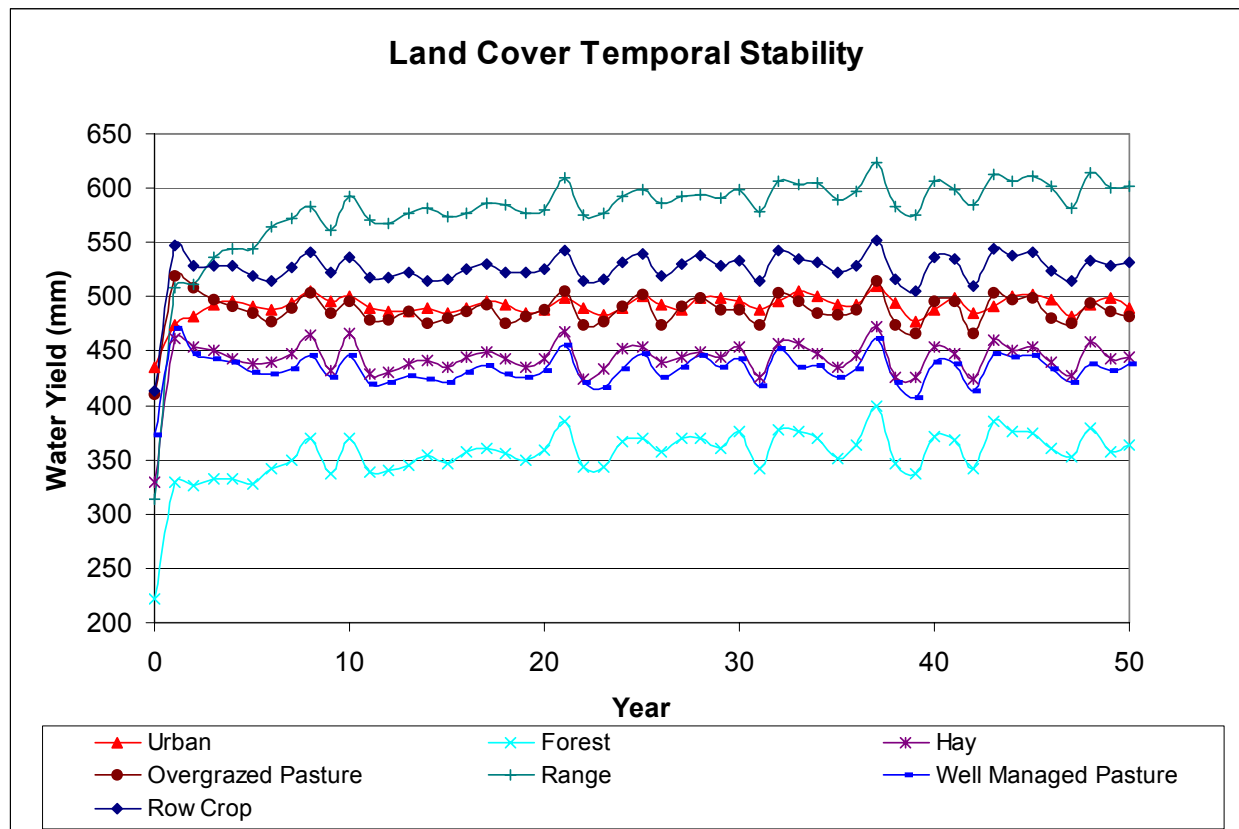


Figure 17 Initial test SWAT model runs to evaluate the temporal stability of land cover types. Performed on a very low detail uncalibrated version of the Lake Eucha/Spavinaw basin model. Using 50 years of identical weather data not necessarily characteristic of the average year.

Soil Phosphorus Content

Two distinctly different methods were used to estimate soil phosphorus content. Pasture and row crop soil phosphorus content were estimated using observed soil test data. Samples for the Oklahoma side of the basin were collected by the Oklahoma Conservation Commission in 1998. These samples had an average of 170 lb/acre soil test phosphorus (STP) for those from pastures and 66 lb/acre STP for those from forests. These are simple averages of the individual soil samples without regard for where they were taken in the basin and should not be confused with an estimate of STP. STP for forested area was not used directly in the SWAT model, but instead was used as a calibration parameter.

Pasture and Row Crop - Soil Phosphorus Content

Observed soil test data were used to estimate the soil phosphorus content for the pasture and row crop portions of each subbasin. Pasture soil samples collected by the Oklahoma Conservation Commission in 1998 and analyzed by the Oklahoma State University (OSU) Soil, Water & Forage Analytical Laboratory were used for the Oklahoma portion of the watershed, which resulted in an average STP of 170 lb P/acre. Soil samples for the Arkansas portion of the basin were provided by the Arkansas Soil and Water Conservation Commission. These data were collected by the

Benton County Conservation District during 1994 through 1997 and analyzed by the University of Arkansas Soil and Water Laboratory. A mean of 334 lb P/acre was derived from 261 pasture soil samples of Benton County.

Soil test phosphorus (STP) data for Oklahoma and Arkansas were analyzed in different labs using slightly different methods. Oklahoma soil samples were analyzed by the Oklahoma State University (OSU) Soil, Water & Forage Analytical Laboratory and Arkansas soil samples were analyzed by the University of Arkansas (UA) Soil Testing and Research Laboratory. OSU and UA use extraction ratios of 1:10 and 1:7, respectively, and use different instrumentation for analysis. OSU uses a colorimetric method and UA uses inductively coupled argon plasma spectrometry (ICAP). Dr. Nathan Slaton with the UA provided the following relationship for different extraction ratios ($n \approx 500$):

$$ICAP_{Mehlich\ III}P(1:10) = 1.27 ICAP_{Mehlich\ III}P(1:7) + 14.9$$

where Mehlich III is in mg/l. Dr. Hailin Zhang with OSU provided the following relationship between ICAP and the colorimetric method ($n=3577$ $R^2=0.98$):

$$ICAP_{Mehlich\ III}P(1:10) = 1.11 Colormetric_{Mehlich\ III}P(1:10) + 26.7$$

where Mehlich III is in mg/l. The average pasture STP level used for the Arkansas portion of the Lake Eucha basin was 334 lbs/ac. Based on these regression equations, an Arkansas STP of 334 lbs/ac corresponds to an OSU value of 372 lbs/ac.

Marshall (1998) developed a nonparametric method to determine the number of samples required, within a 90% confidence interval, to estimate subbasin soil test phosphorus by land use for hydrologic/water quality modeling. This method was applied to the Lake Eucha Basin, and a soil sampling plan was developed for pastures and forested areas. The Oklahoma Conservation Commission was contracted to collect these soil samples for the Oklahoma portion of the basin. The number of samples collected in each subbasin is shown in Table 4.

Soil samples from the Oklahoma Conservation Commission were double checked to ensure that their locations were within the indicated subbasin. Some 14 samples fell outside the Lake Eucha basin or were unusable for other reasons. Samples less than 400 meters outside the basin were reassigned to the nearest subbasin (Table 5). Because SWAT defines its own subbasins, an approximation of Marshall's (1998) original subbasin theme was used to determine where the samples were taken (Figure 18). An area weighted soil test phosphorus was calculated for each of SWAT's 58 subbasins (Figure 19).

Table 4 Number of soil samples from each major tributary used to calculate subbasin average soil test phosphorus for pasture and row crop used in SWAT.

Basin	Pasture Total	Forest Total
Eucha	5	3
Dry	25	11
Brush	29	5
Beaty	46	3
Cloud	33	4
Cherokee	41	5
Black Hollow	33	

Table 5 Pasture and row crop soil test averages by tributary Oklahoma portion only).

Subbasin	PH	Buffer Index	N (lb/acre)	Melich III P (lb/acre)	K (lb/acre)
Eucha	6	7	17	91	323
Dry	6	7	14	69	306
Brush	6	7	11	150	268
Beaty	6	5	24	202	337
Cloud	5	7	9	120	291
Cherokee	6	6	26	297	363
Black Hollow	5	7	53	112	267

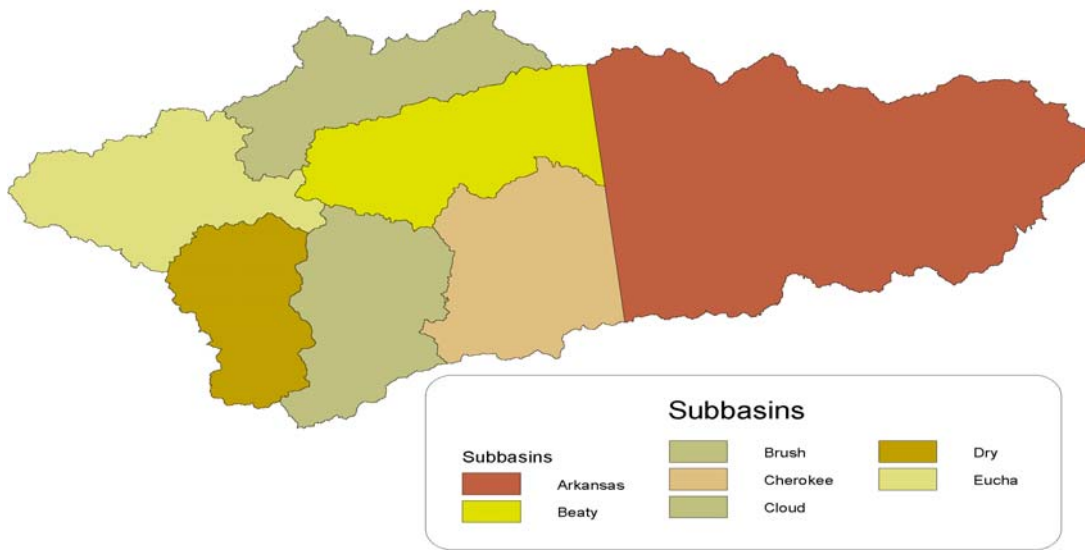


Figure 18 Approximation of Marshall (1998) original subbasins.

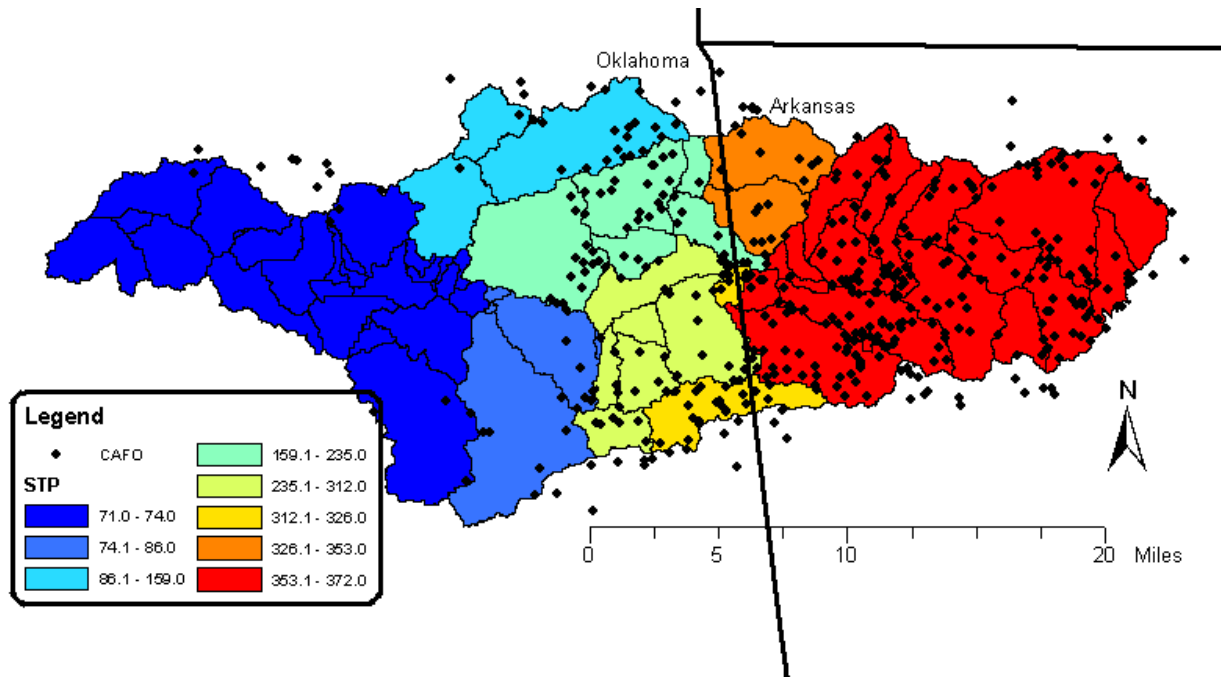


Figure 19 Mehlich III soil test phosphorus (STP) for pastures and row crop by subbasin for the Lake Eucha/Spavinaw Basin. Dots indicate poultry house locations.

Poultry Litter Application Rate

The number of poultry houses and the pasture area in each subbasin were used to determine poultry litter application rates. All litter produced in a subbasin was assumed to be uniformly applied to pastures in that subbasin.

Simmons Foods Inc. provided locations of several company farms which export poultry litter from the basin. The initial litter application rate was reduced in these areas to account for the exported litter. A total of 5883 ton/yr was exported. Other integrators also export litter but the locations of their houses were not available, and thus we were unable to remove the litter from the proper subbasins. It should be noted, however, that Simmons Foods Inc. represented a significant portion of the exported poultry litter in the basin.

Broiler, layer, and turkey production all contribute to the total litter production. Each type of operation produces a different amount of litter, and litter of a different composition (Table 6a). The amount of litter contributed basin-wide by each type of operation is summarized in Table 6b. The average litter composition was determined by using the relative amount of each litter applied in the basin and its composition (Table 7).

The average amount of poultry litter applied to pastures was 1830 kg/ha (0.81 ton/acre). This is the total amount of litter produced in the basin divided by the total area of pasture and row crop. Because many pastures receive little or no poultry litter the average application rate would be somewhat higher. The maximum poultry litter rate was assigned to subbasin 52, 9310 kg/ha (4.1 ton/acre), which reflects the high number of poultry operations located in the small subbasin (Figure 20). A total of 91,700 tons of poultry litter was estimated to be applied in the Eucha/Spavinaw Basin each year. This poultry litter contained approximately 1,140,000 kg phosphorus (1260 ton)

and 3,800,000 kg nitrogen (4190 ton).

Table 6a Annual poultry litter production by house in the Lake Eucha/Spavinaw Basin and fractional composition by operation type. (Broilers assumed 5 batches per year)

Operation	Litter per 20,000 animal capacity	Mineral N	Mineral P	Organic N	Organic P	Source
Broiler	100 ton/yr	0.01000	0.00400	0.04000	0.01000	Storm et al. (1999) and SWAT Database
Layer	200 ton/yr	0.01300	0.00600	0.04000	0.01300	Finley (1994) and SWAT Database
Turkey	310 ton/yr	0.00700	0.00300	0.04500	0.01600	Vest (1994) and SWAT Database

Table 6b Poultry litter production in the Lake Eucha/Spavinaw Basin by operation type.

Type	Litter production t/yr	Realtive litter production
Broilers	72684	79.3%
Genetic	3000	3.3%
Genetic & Broiler	1200	1.3%
Layers	8200	8.9%
Pullets	1900	2.1%
Turkeys	4720	5.1%
Total	91704	100%

Table 7 Average fraction nutrient concentration of poultry litter produced in Lake Eucha/Spavinaw Basin.

Type	Realtive litter production	Mineral N	Organic N	Mineral P	Organic P
Broilers	79%	0.010	0.040	0.004	0.010
Genetic	3%	0.013	0.040	0.006	0.013
Genetic & Broiler	1%	0.010	0.040	0.004	0.010
Layers	9%	0.013	0.040	0.006	0.013
Pullets	2%	0.010	0.040	0.004	0.010
Turkeys	5%	0.007	0.045	0.003	0.016
Average		0.0102	0.0403	0.0042	0.0107
Used in SWAT Model		0.010	0.040	0.004	0.011

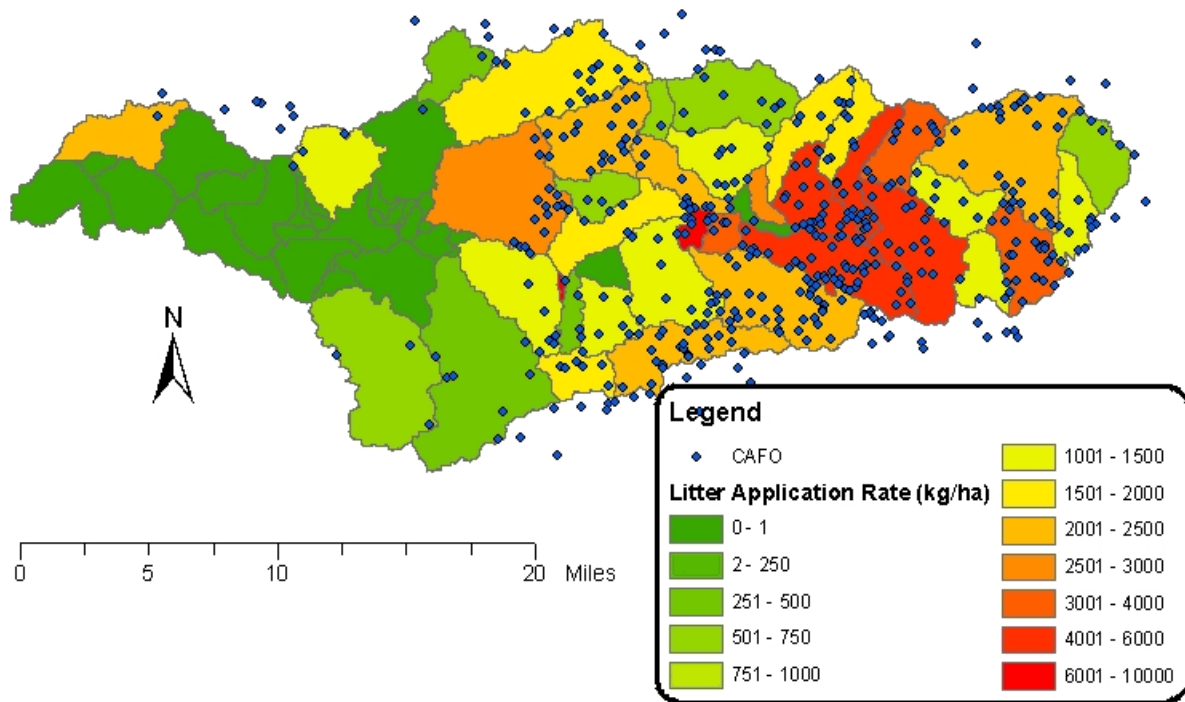


Figure 20 Poultry Litter applied by subbasin and poultry house locations (black dots) for the Lake Eucha/Spavinaw basin.

Commercial Fertilizer Applications

To simplify the management input files, commercial nitrogen and phosphorus fertilizer sales in 1998 and 1999 for Delaware County, Oklahoma and Benton County, Arkansas were assumed to be uniformly applied to row crop in each county. Yearly rates for both counties were area weighed to estimate a single annual application rate for row crop the basin (32 kg/ha nitrogen and 0.42 kg/ha phosphorus). Phosphorus inputs from commercial fertilizer were negligible compared to inputs from poultry litter.

Observed Stream Flow

The Lake Eucha/Spavinaw Basin contains three USGS stream gages (Figure 21). These gages were used to calibrate the hydrologic portion of the model. Each gage station has a different period of record (Table 8.)

Table 8 Available period of record at U.S. Geographic Survey stream gage stations.

Gage Station	Start Date	End Date
Spavinaw Creek Near Sycamore	10/1/1961	Current
Beaty Creek Near Jay	7/31/1998	Current
Black Hollow Near Spavinaw	7/24/1998	9/30/2001

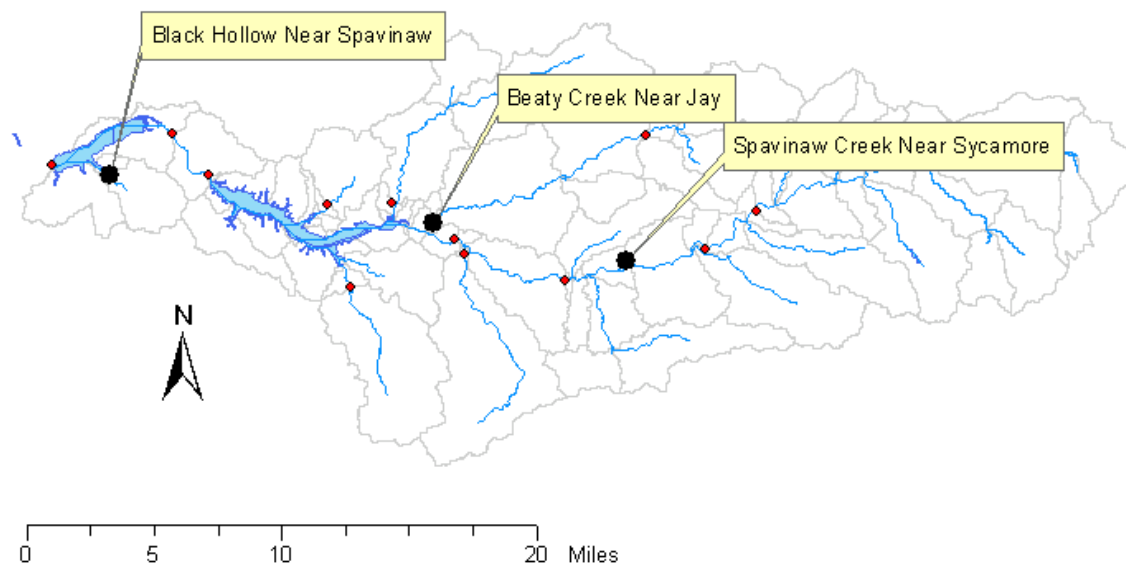


Figure 21 Active U.S. Geographic Survey stream gage stations used to calibrate the SWAT model for the Lake Eucha/Spavinaw Basin. (Red dots represent the City of Tulsa water quality stations)

Baseflow Separation

Stream flow has two primary sources, surface runoff and ground water. Ground water contributions to stream flow are known as baseflow. The SWAT model was calibrated separately against observed surface and baseflow. Baseflow was separated from the total observed stream flow using the USGS HYSEP sliding interval method. The duration of surface runoff is calculated from the empirical relationship:

$$N = A^{0.2}$$

where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval $2N^*$ used for hydrograph separations is the odd integer between 3 and 11 nearest to $2N$. We adjusted the interval to provide a range of baseflow values. The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [$0.5(2N^*-1)$ days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar $2N^*$ wide upward until it intersects the streamflow hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated. Baseflow fractions were relatively high throughout the basin, likely the result of the karst topography (Table 9). Karst features allow significant interaction between stream flow and ground water (Wagner and Woodruff 1997).

Table 9 Observed average flow and baseflow fractions as determined by the HYSEP sliding interval method.

Gage	Total Flow	Surface Runoff	Baseflow	Period
Blackhollow	0.109	36% - 22%	78% - 64%	8/98 to 9/01
Beaty Creek	1.33	59% - 52%	48% - 41%	8/98 to 3/02
Spavinaw Creek	3.3	60% - 43%	57% - 39%	8/98 to 3/02

Observed Loading Development

Water quality data were available for 10 suitable locations in the basin. Soluble and total phosphorus and nitrate loads were estimated at each of these stations (Figure 22). SWAT was calibrated for nutrients after the hydrologic calibration was completed.

Flow was estimated at each water quality station where flow data were unavailable. Initially, daily flow was estimated from the closest stream gage and assumed flow was proportional to drainage area. Flow data before 8/1998 were estimated from the Spavinaw station only, because Spavinaw was the only active station before 8/1998. To further refine the estimate, the flow at each station was separated into surface and baseflow fractions. The ratio of daily precipitation for the area above each water quality station and the area above each gage was used to bias surface runoff estimates. Baseflow fractions were not corrected. Surface runoff adjustments were limited to a maximum of three times and a minimum of 1/3 the original value. This procedure was evaluated at the USGS Beaty Creek gage using flow at the USGS gage on Spavinaw Creek. The results are displayed in Figure 22. Nash-Sutcliffe coefficient for this rainfall bias estimate for Beaty Creek yielded 0.742 and without the rainfall correction the Nash-Sutcliffe coefficient was reduced to 0.533.

Nutrient Loading

Nutrient loads were estimated by station using the USGS DOS program LOADEST2 (Crawford, 1996). This program was developed by Charles Crawford (USGS Supervisory Hydrologist) to estimate loading using the rating curve method. The software has 10 models from which to choose, with models 1-8 are listed below:

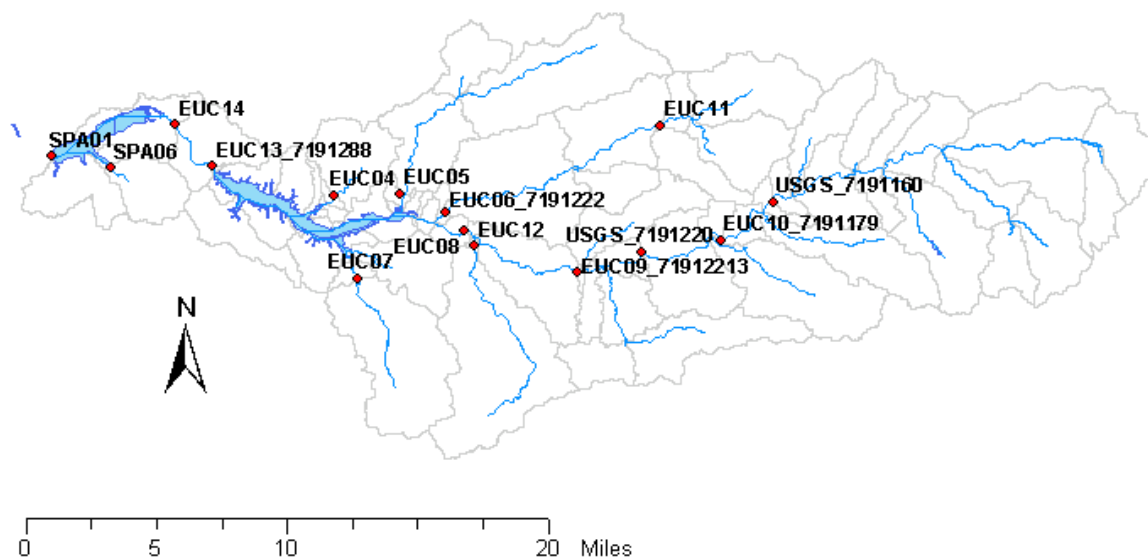


Figure 22 City of Tulsa and US Geographic Survey water quality station locations.

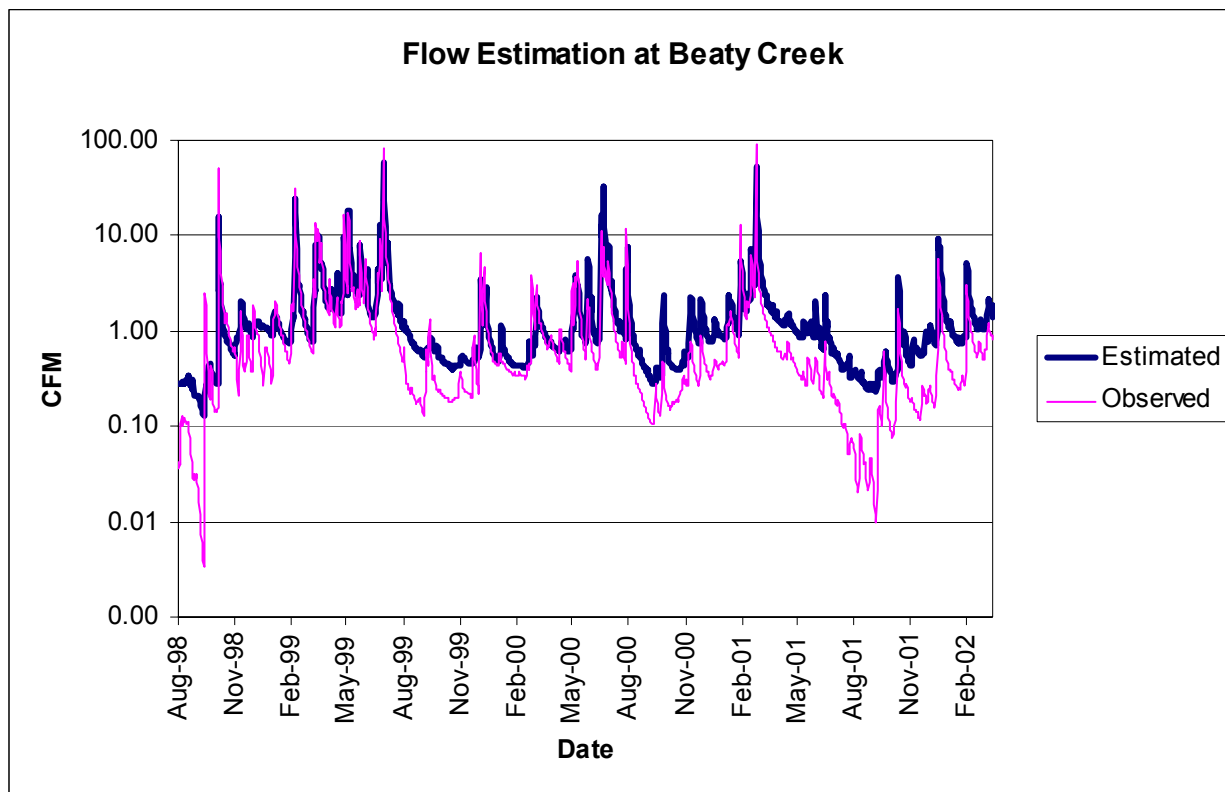


Figure 23 Observed and rainfall corrected estimates of Beaty Creek stream flow using data from the Spavinaw Creek gage for the period August 1998 to March 2002.

model 1: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow})$

model 2: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \ln(\text{flow})^2$

model 3: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \text{dectime}$

model 4: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \sin(\text{dectime}) + b_3 \cos(\text{dectime})$

model 5: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \ln(\text{flow})^2 + b_3 \text{dectime}$

model 6: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \ln(\text{flow})^2 + b_3 \sin(\text{dectime}) + b_4 \cos(\text{dectime})$

model 7: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \sin(\text{dectime}) + b_3 \cos(\text{dectime}) + b_4 \text{dectime}$

model 8: $\ln(\text{load}) = b_0 + b_1 \ln(\text{flow}) + b_2 \ln(\text{flow})^2 + b_3 \sin(\text{dectime}) + b_4 \cos(\text{dectime}) + b_5 \text{dectime}$

Dectime is time in fractional years.

Each of these 8 models was used by LOADEST2 at each station. At each station 2 to 3 models were selected based on the estimated residual variance calculated by LOADEST2. These 2 to 3 models were then graphed as observed vs predicted concentrations. Visual comparisons of each graph and the estimated residual variance for each model were used to select the best model at each station (Table 10).

Table 10 Model type, estimated observed phosphorus load, and water quality data observations by station using Loadest2 (includes both point and nonpoint sources).

Station	Type	Model	LOAD kg/yr	Uncensored Observations
EUC04	Total P	4	166	26
EUC05	Total P	8	2489	33
EUC06	Total P	8	8461	218
EUC07	Total P	5	1161	40
EUC08	Total P	8	34841	174
EUC09	Total P	2	24886	71
EUC10	Total P	1	16591	67
EUC11	Total P	6	3982	68
EUC12	Total P	3	813	13
SPA06	Total P	6	114	74
EUC04	Soluble P	8	11	25
EUC05	Soluble P	8	979	32
EUC06	Soluble P	8	3650	137
EUC07	Soluble P	4	159	38
EUC08	Soluble P	8	14268	134
EUC09	Soluble P	8	23227	71
EUC10	Soluble P	7	16591	67
EUC11	Soluble P	8	1327	68
EUC12	Soluble P	1	498	13
SPA06	Soluble P	6	41	51
EUC04	Nitrate as N	4	5475	28
EUC05	Nitrate as N	8	23227	35
EUC06	Nitrate as N	8	114477	221
EUC07	Nitrate as N	7	10618	48
EUC08	Nitrate as N	6	514318	176
EUC09	Nitrate as N	6	530909	70
EUC10	Nitrate as N	8	365000	66
EUC11	Nitrate as N	6	64705	67
EUC12	Nitrate as N	7	33182	13
SPA06	Nitrate as N	6	2489	68

Point Source Loadings

Although most of the nutrient loading was attributed to non-point source pollution, one significant point source is located in the Lake Eucha/Spavinaw Basin at the City of Decatur, Arkansas. A poultry processing plant is located in City of Decatur, with waste from the plant processed by the City of Decatur waste water treatment plant. The treatment plant discharges to Colombia Hollow. The US Environmental Protection Agency PCS (Permit Compliance System) contains estimated monthly loading from Decatur (NPDES ID AR0022292). Only the average daily load was used (Table 11).

Table 11 City of Decatur, Arkansas point source average daily load for the period 1-98 to 3-02.

Parameter	Total P	Nitrate-N	Flow	Ammonia-N
Units	kg/day	kg/day	m ³ /day	kg/day
Value	32	10	4829	40

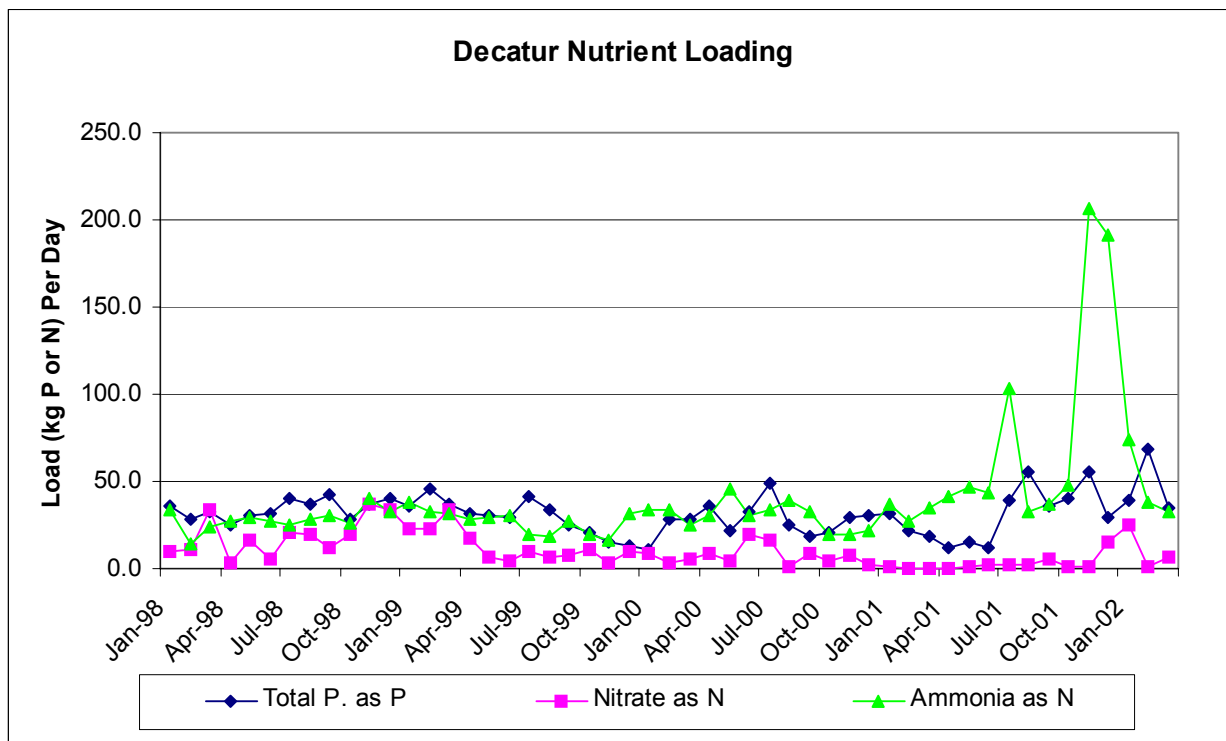


Figure 24 City of Decatur, Arkansas point source loading trends. Derived from the Environmental Protection Agency's Permit Compliance System.

Calibration

The SWAT model was calibrated using observed stream and nutrient data. Three stream gage stations and eight water quality stations were used in the calibration. The model was calibrated for total flow, surface flow, baseflow, soluble phosphorus, and total phosphorus.

The model was first calibrated on stream flow at each of the three gages. Observed stream flow was split into surface runoff and baseflow. After the hydrologic calibration the model was calibrated for nutrients. SWAT model predicted loads were compared to loads estimated from samples taken at eight water quality stations, and relative error was calculated at each station. The relative error in load at each station was weighted by the area upstream each station and the number of high flow samples at that station were used to develop a single basin wide relative error. This average relative error was used to guide the nutrient calibration. The sum of the absolute relative error at all stations was also calculated and used as a secondary guide during the calibration.

$$\text{Relative Error (\%)} = (\text{Predicted} - \text{Observed}) / \text{Observed} * 100 \%$$

Hydrologic calibration

Three gage stations, shown in Figure 25, were used in the calibration of total flow, surface runoff, and base flow. All available streamflow for the calibration period (8/1/1998 to 3/15/2002) were utilized. The period of available data from the three stations is not the same. Spavinaw Creek have data prior to 8/98 but it was not included in the calibration to allow a single calibration period for all stations.

We split the basin into three areas, each with a different set of calibration parameters. Subbasins not upstream of a gage were lumped with the most similar adjacent calibrated area. Land use, topography, geology, and location were used to determine subjectively how to lump each subbasin. Relative error was used to compare observed and predicted data and to guide the calibration process.

Modifications to model parameters were required to calibrate the model and are given in Table 12. Parameters governing ground water were modified to compensate for the karst topography of the region. Results of the calibration are shown in Table 13. Note relative error was less than 5% for the Spavinaw and Beaty Creek gages. Blackhollow was calibrated by visual comparison between observed and predicted flows, and thus the average annual relative error is not a good measure of the quality of the calibration at this station. The visual calibration was required due to long dry periods with no flow observed at the gage. Figures 26, 27, and 28 detail the results of the calibration at each of the three stations.

Nutrient Calibration

The nutrient calibration was performed in a different manner than the hydrologic calibration, because many nutrient parameters are not specific to land covers or subbasins. A slightly different period was also used to calibrate the nutrient portion of the model, i.e. 1-1-98 to 3-15-2002. The hydrologic calibration did not begin until 8-1-98. The basin was calibrated as a whole using comparisons at all stations simultaneously.

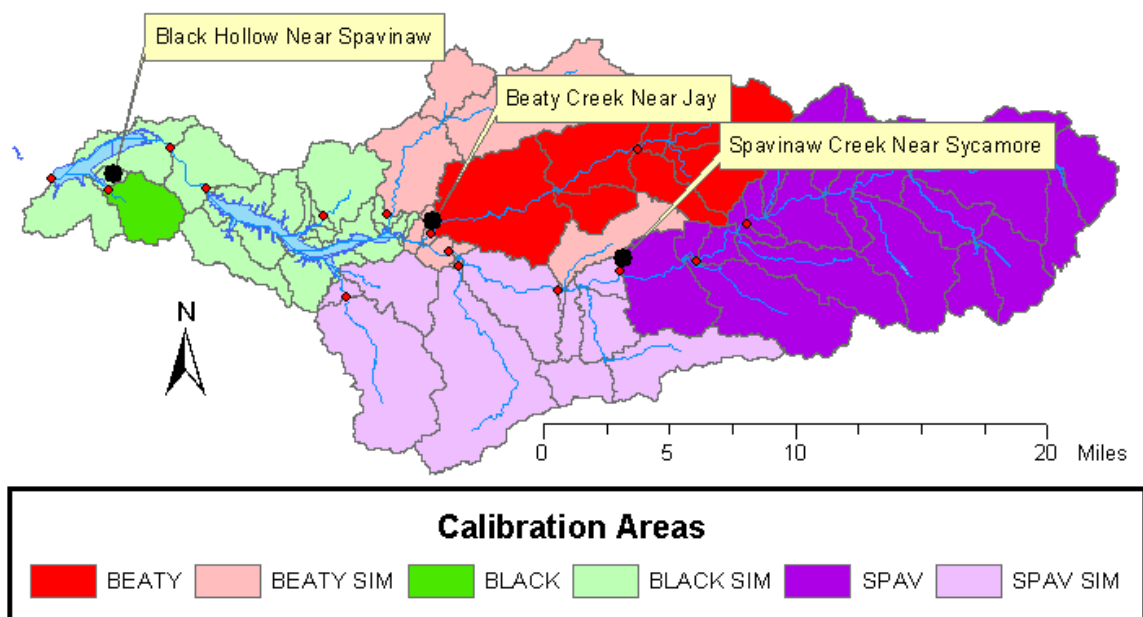


Figure 25 SWAT calibration regions for the Eucha/Spavinaw Basin (SIM denotes an area that is not upstream of a gage station).

Table 12 Parameter modifications made to calibrate the hydrologic portion of the SWAT model.

Parameter	Spavinaw	Beaty	Blackhollow
Initial depth of water in shallow aquifer (mm)	100	100	100
Baseflow delay (days)	1	1	1
Alpha baseflow factor	0.11	0.11	0.11
Min depth in shallow aquifer for baseflow (mm)	30	30	30
Revap Coff.	0.02	0.02	0.02
Min depth in shallow aquifer for revap (mm)	10	10	10
Fraction of shallow aquifer directed to deep aquifer	0.17	0.17	0.7
Mannings N for overland flow	0.15	0.15	0.15
Soil Evaporation Compensation Factor	0.63	0.63	0.63
Curve number adjustment	-5	0	-5
Channel permeability (mm/hr)	100	100	100
Mannings N for channel	0.1	0.1	0.1
Pond bottom permeability (mm/hr)	3	3	3

Table 13 Average annual results for the hydrologic calibration of the SWAT model at each USGS streamflow gage.

Gage	Observed			Predicted			Relative Error
	Total Flow	Surface Runoff	Baseflow	Total Flow	Surface Runoff	Baseflow	
Blackhollow	0.109	36% - 22%	78% - 64%	0.094	53%	47%	-13.7%
Beaty Creek	1.33	59% - 52%	48% - 41%	1.37	52%	48%	2.9%
Spavinaw Creek	3.3	60% - 43%	57% - 39%	3.45	48%	52%	4.4%

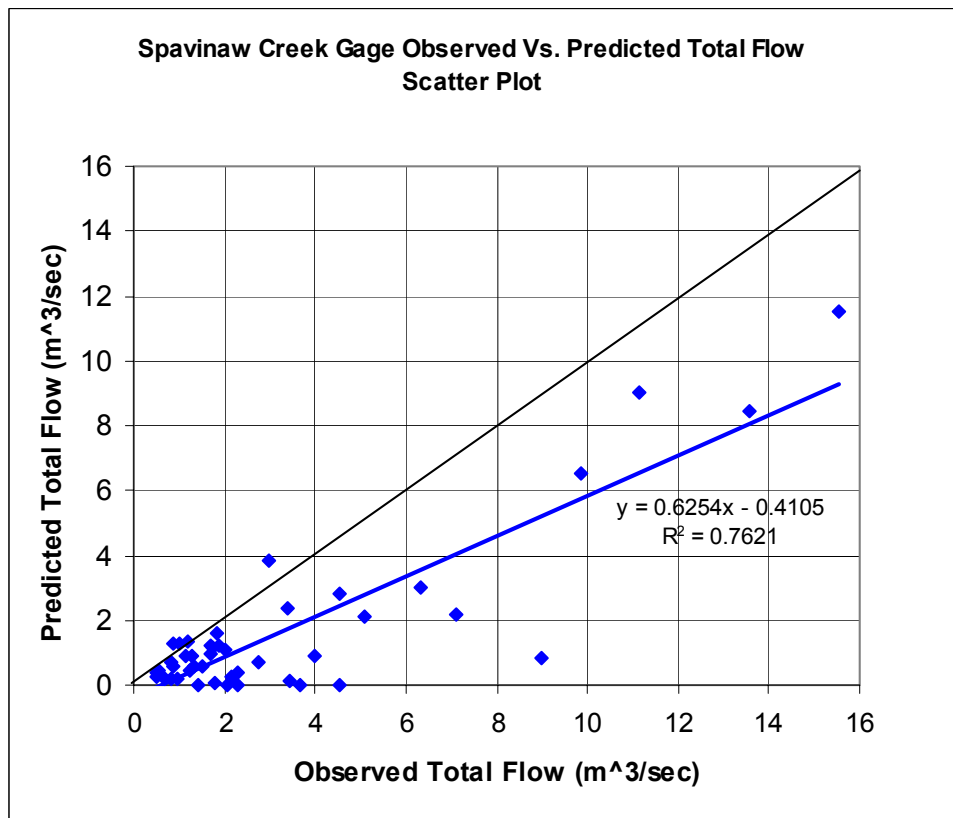
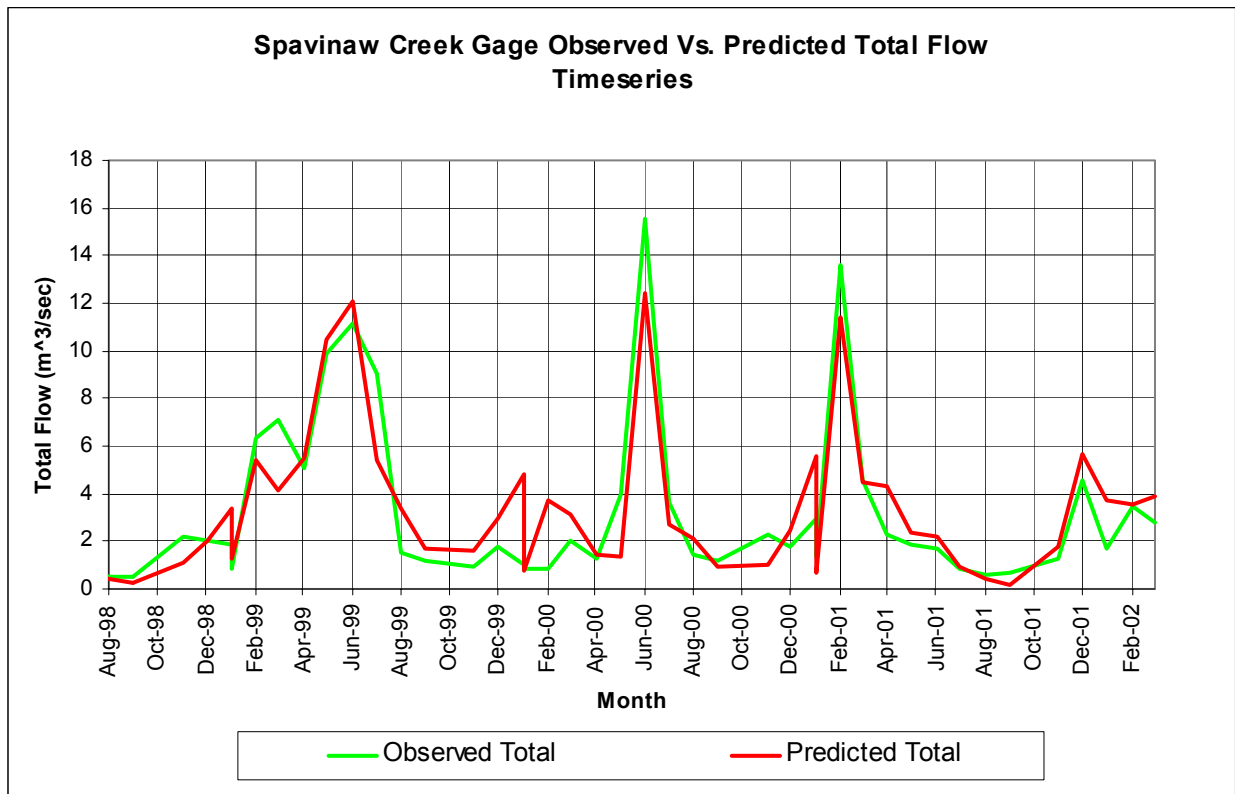


Figure 26 Calibration results at Spavinaw Creek gage for the period 8/1/1998 to 3/15/2002.

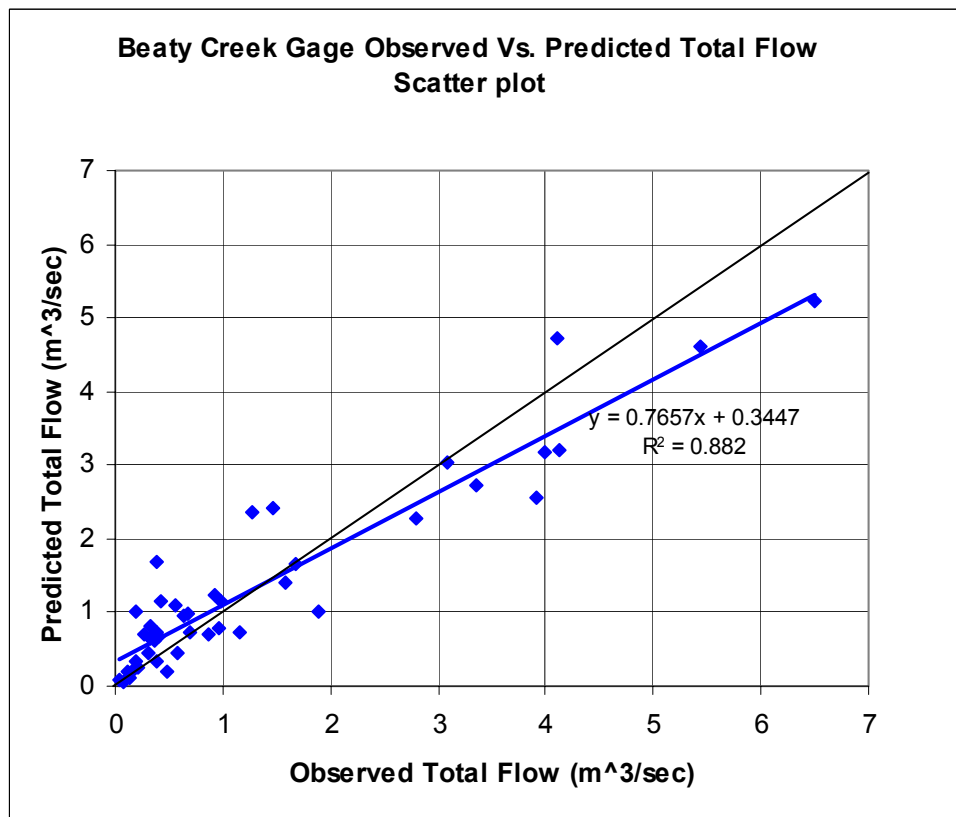
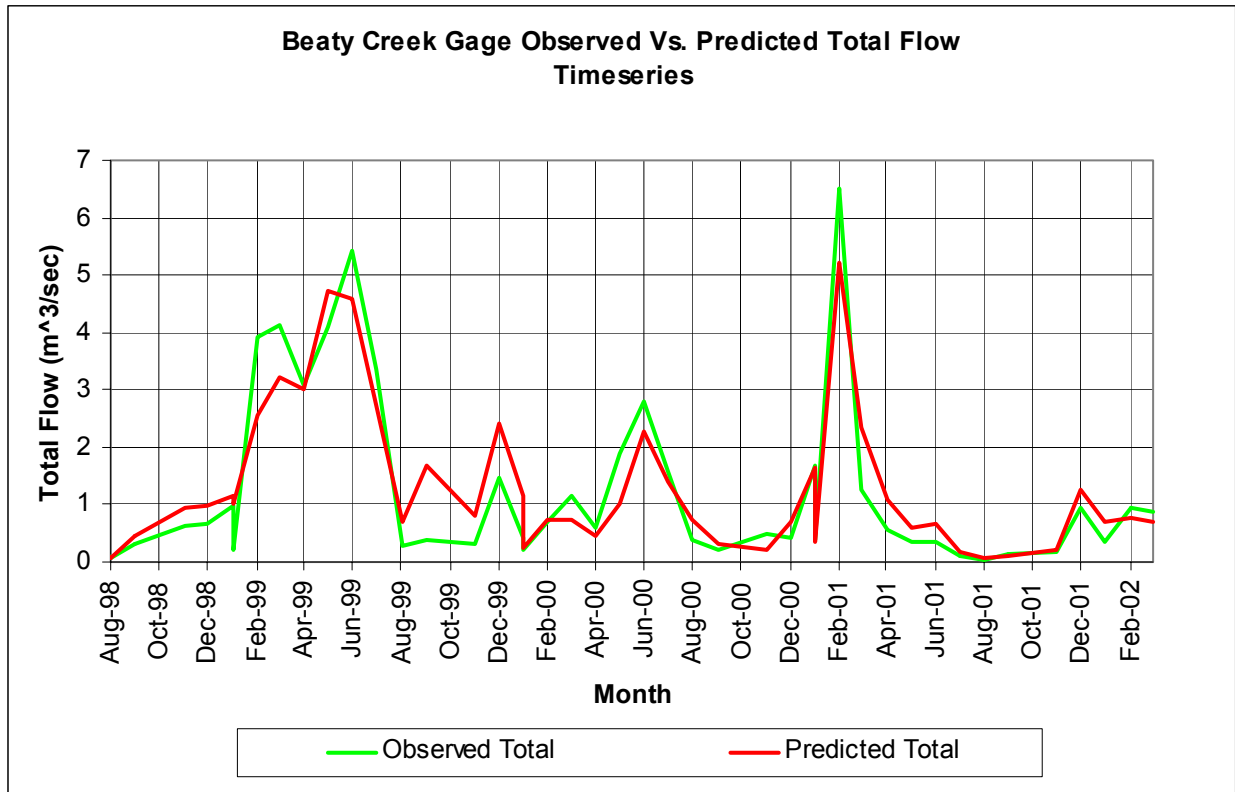


Figure 27 Calibration Results at Beaty Creek gage for the period 8/1/1998 to 3/15/2002.

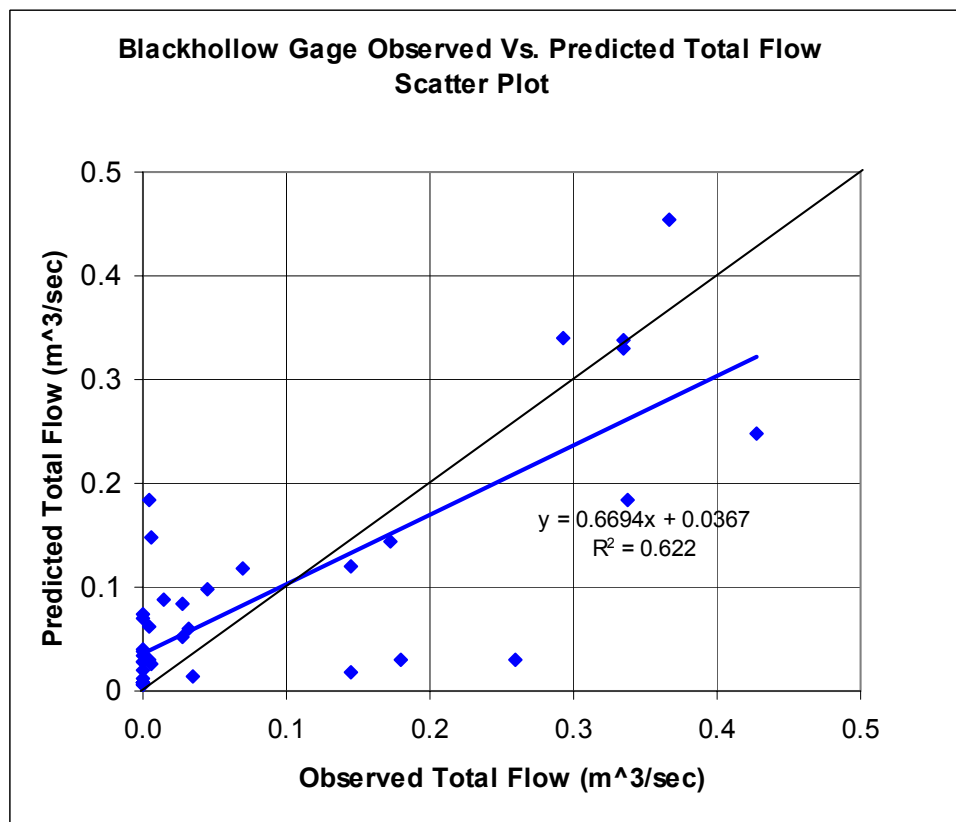
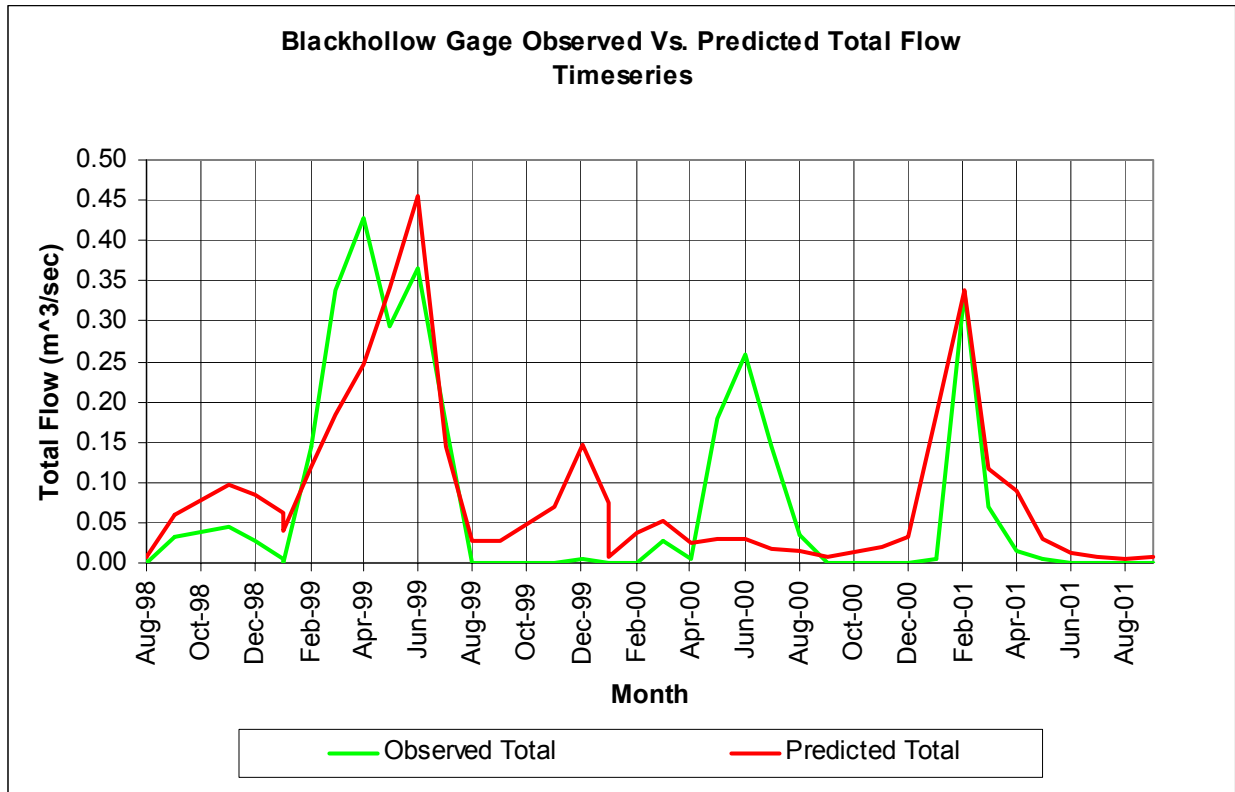


Figure 28 Calibration Results at Blackhollow gage for the period 8/1/1998 to 9/30/2002.

Sediment was included in the calibration process because of its impact on nutrient load. No recent sediment data were available and thus sediment loss was adjusted to literature based levels (Table 14). SWAT uses the Modified Universal Soil Loss Equation (MUSLE) to calculate sediment yield. The MUSLE C factor is calculated internally from the total of surface residue and biomass and a minimum C factor. This minimum C factor can be related to the average annual C by the following set of equations:

$$MC = EXP(1.463 \ln(CVA) + 0.1034)$$

where **MC** is the minimum C factor and **CVA** is the average annual C factor. The sensitivity of SWAT to minimum C factor is low, and 0.001 is the lowest value allowed by the model. Therefore, it was necessary to adjust the P factor for pastures to 0.07 to further reduce sediment loading. The P factor was treated as a calibration parameter in this case.

Table 14 Minimum C Factor and SWAT predicted sediment loss by land cover for the Lake Eucha/Spavinaw basin for the period 1-1-98 to 3-15-2002.

Land Cover	Minimum C Factor	Sediment Yield MT/ha
Urban	0.003	0.189
Forest	0.001	0.047
Hay	0.001	0.010
Poorly Managed Pasture	0.001	0.113
Range	0.002	0.093
Water	0	0.000
Well Managed Pasture	0.001	0.003
Row Crop	0.03	7.790

Phosphorus

Observed and predicted loads at 8 of the 10 stations were compared. The remaining two stations had little high flow sampling and were considered too uncertain for use in the calibration. Relative error was calculated at each station for soluble and total phosphorus. These relative errors were area weighted according to the contributing area at each water quality station and the number of high flow samples; the result was used to guide the calibration. The result of the nutrient calibration is shown in Table 15.

Some observed loads are calculated from samples taken downstream the City of Decatur point source. To quantify nonpoint source loading from the observed data, we remove the loading from City of Decatur point source by assuming the load was 90% soluble and simply subtracted it from all stations downstream. In reality much of this soluble phosphorus would be assimilated into the biota and only be measurable via total phosphorus. We do not have data to directly estimate how much of the point source load would be soluble when it reaches each of the downstream stations, and therefore our assumption was conservative. To compensate we allowed an over prediction by the SWAT model for soluble P of 22%. If we had we chosen 80% instead of 90% for the solubility of the point source the error in soluble P would have been lowered to 2%.

Relative error at any given station may be off by a substantial amount. Because the majority of the parameters are not distributed, it is not possible to make an adjustment at one station without affecting all other stations. In addition, many stations do not have sufficient high flow sampling to accurately estimate loadings and thus little relative weight was given to these stations in the

calibration process. The following parameters were adjusted basin wide in the basin input file (Basins.bsn):

NPERCO (Nitrogen Percolation Coefficient) = 2
 PPERCO (Phosphorus Percolation Coefficient) = 3
 PHOSKD (Phosphorus Soil Partitioning Coefficient) = 800
 PSP (Phosphorus Sorption Coefficient)= 0.42

Additional parameters such as Biological Mixing Efficiency (BIOMIX) and Minimum Biomass for Grazing were also modified by land cover. These values are listed in Table 16.

STP was used to calibrate the nutrients from forested areas. Modifications to basin wide phosphorus parameters were required to calibrate the model form its response to surface application of poultry litter. These modifications required an increase in labile P in forested areas to 40 mg/kg to maintain satisfactory total P loading from heavily forested areas like Blackhollow.

Table 15 Observed and SWAT predicted average nonpoint source (NPS) annual nutrient load at City of Tulsa water quality stations for the period January 1998 to March 2002. City of Decatur point source loading removed from relevant stations assuming load is 90% soluble and is not modified instream. High flow sample is defined as three times the average flow; a maximum of two high flow samples are counted for each day. Relative weight is based on the number of high flow samples and the area above the station.

Station	AREA km ²	High Flow Total P Samples	Relative Weight	Observed Total P kg/yr	Predicted Total P kg/yr	Relative Error Total P	Observed Soluble P kg/yr	Predicted Soluble P kg/yr	Relative Error Soluble P
EUC04	20.9	4	1%	166	164	-1%	11	61	449%
EUC05	87.1	4	3%	2,489	2,846	14%	979	543	-45%
EUC06	153.0	28	31%	8,461	7,610	-10%	3,650	1,811	-50%
EUC07	50.6	2	1%	1,161	564	-51%	159	127	-20%
EUC08	517.6	16	61%	23,341	24,822	6%	3,918	6,401	63%
EUC11	65.9	4	2%	3,982	3,620	-9%	1,327	943	-29%
EUC12	64.3	2	1%	813	1,219	50%	498	209	-58%
SPA06	15.6	12	1%	114	101	-12%	41	5	-88%
Average Weighted Realtive Error						1%			22%

Table 16 Management parameters used to calibrate the nutrient portion of the SWAT model.

Land Cover	Biomix	BIO_MIN (kg/ha)
Hay	0.2	N/A
Poorly Managed Pasture	0.2	800
Well Managed Pasture	0.2	1600
Urban	0.05	N/A
Row Crop	0.05	600
Forest	0.05	N/A
Range	0.05	N/A

Model Predictions

A great deal of information can be derived from the calibrated SWAT model. The magnitude and source of the load entering Lake Eucha were estimated. Additional simulations allow us to estimate the uncertainty in our predictions due to rainfall and background loading.

Simulated Nutrient Loading

Nutrient loads were simulated at important locations throughout the basin. The nutrient load to Spavinaw Lake cannot be directly predicted since SWAT cannot accurately simulate the processes that occur in Lake Eucha. However, a load estimate for the area between Lakes Spavinaw and Eucha was required to determine if this area is a significant source of nutrients (Figure 29). Loading from the small portion of the basin between the Lake Eucha dam and Spavinaw Lake was insignificant (1.5%) when compared to the loading to Eucha Lake (Table 17). This report focuses on the Lake Eucha basin, and all charts and figures pertain to this area unless otherwise stated.

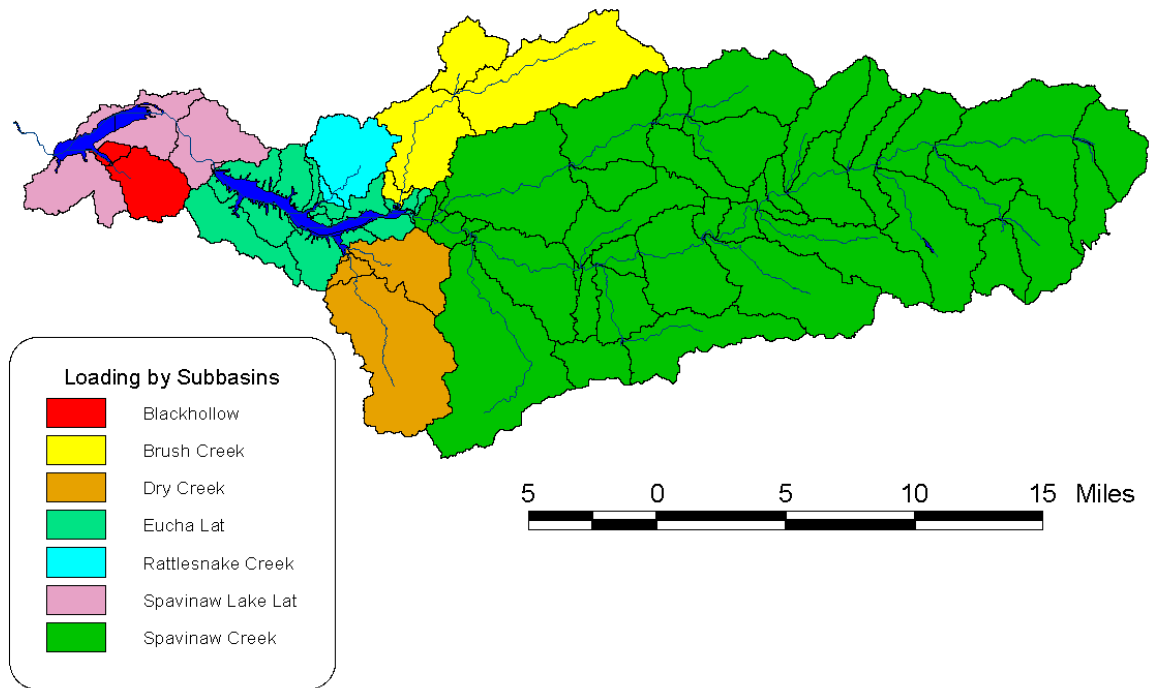


Figure 29 Contributing areas at each location for SWAT model predictions. The contributing area for Spavinaw Creek includes Beaty, Cloud, and Cherokee Creeks.

Table 17 SWAT simulated average annual nutrient load from nonpoint sources from January 1998 to March 2002. Spavinaw Creek includes Beaty, Cloud, and Cherokee Creeks.

Area	Flow (m ³ /sec)	Total P (kg P/yr)	Soluble P (kg P/yr)
EUC04	0.13	164	61
EUC05	0.87	2,846	543
EUC06	1.51	7,610	1,811
EUC07	0.51	564	127
EUC08	5.40	24,822	6,401
EUC09	4.53	20,645	5,892
EUC10	3.06	13,796	4,374
EUC11	0.55	3,620	943
EUC12	0.60	1,219	209
SPA06	0.09	101	5
Lake Eucha	NA	36,765	9,014
Entire	NA	37,343	9,069
Blackhollow	0.10	113	5
Brush	0.88	2,856	544
Dry	0.54	820	151
Lake Eucha Laterals	NA	418	37
Rattlesnake	0.13	169	62
Spavinaw Laterals	NA	466	49
Spavinaw Creek	6.97	32,502	8,222

Background Loading Estimates

Background loading was estimated by simulating the entire basin as forest, using the flow calibration from Black Hollow. Black Hollow was used because it contains a higher fraction of forest than the other two calibration areas.

The anthropogenic effects appear to be large; NPS total phosphorus was estimated to increase by 900%. Including the City of Decatur the increase is 1,150%. This increase is a result of many factors; litter application and the resulting increase in STP appear to be the largest contributors, but changing forest to pasture and row crop are also important factors.

Uncertainty Analysis

The uncertainty associated with water quality models is difficult to quantify. According to MacIntosh et al. (1984), there are two major types of uncertainty, knowledge uncertainty and stochastic uncertainty. Knowledge uncertainty stems from measurement errors and the inability of the model to accurately simulate the physical, chemical, and biological processes. Stochastic uncertainty is due to the random nature of natural systems, like rainfall. Rainfall is the driving force behind nutrient transport. Because rainfall is so important, it represents a major source of uncertainty. One method to quantify this uncertainty is to perform many simulations of the same scenario using different rainfall records. In this manner we can quantify the stochastic uncertainty associated with natural temporal variability in rainfall. We generated statistics from 30 simulations using weather data from 1965 to 1999 to estimate confidence intervals. This procedure accounts for only stochastic uncertainty associated with rainfall.

Thirty simulations were performed for each scenario, with observed rainfall records for the period

1/1/65 to 12/31/99. Each simulation covered a total of 6 years, the first 5 years allow the model to “warm-up” so that initial conditions are less important (Figure 30). Only data from the last year of the simulation were used. Custom software was written specifically to perform these simulations. The computational requirements to perform such simulations are enormous. In excess of 60 hours of processing time were often required to perform a single set of simulations.

An underlying distribution was assumed and tested before confidence intervals were estimated. The results from 30 simulations of the calibrated model were analyzed and a lognormal distribution was deemed acceptable (Table 18). By assuming a distribution, we can determine the probability that loading will be in a particular range (Figure 31 and 32) and estimate confidence intervals.

The effect of rainfall variations on the system is dramatic, thus the confidence intervals are quite large (Tables 19 and 20). Rainfall has such a major effect that it can mask BMP effects for a particular year. Monthly uncertainty was not calculated due to the extreme variability in monthly loading, however an average is depicted in Figure 33.

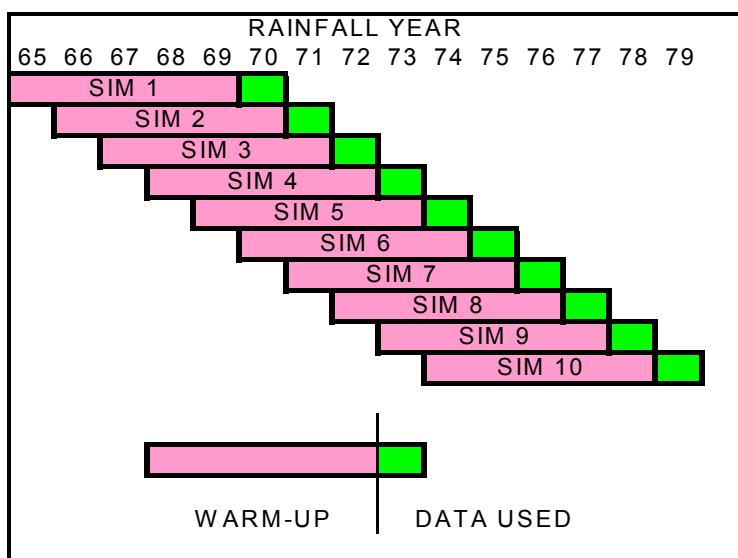


Figure 30 Simulation timing for the rainfall uncertainty analysis with SWAT.

Table 18 Assigned statistical distribution used to determine confidence intervals for SWAT prediction.

Output Parameter	Distribution
Flow	LogNormal
Soluble P	LogNormal
Sediment Bound P	LogNormal

Table 19 Calibrated SWAT model nonpoint source prediction statistics derived from 30 simulations. Spavinaw refers to the small portion of the basin that drains exclusively to Spavinaw Lake.

Area	Flow (m ³ /sec)		Water Yield (mm/yr)		Total P (kg/yr)		Soluble P (kg/yr)	
	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
Spavinaw	NA	NA	130	82	465	424	42	52
Eucha	7.74	4.48	263	151	30,444	19,039	9,523	4,542

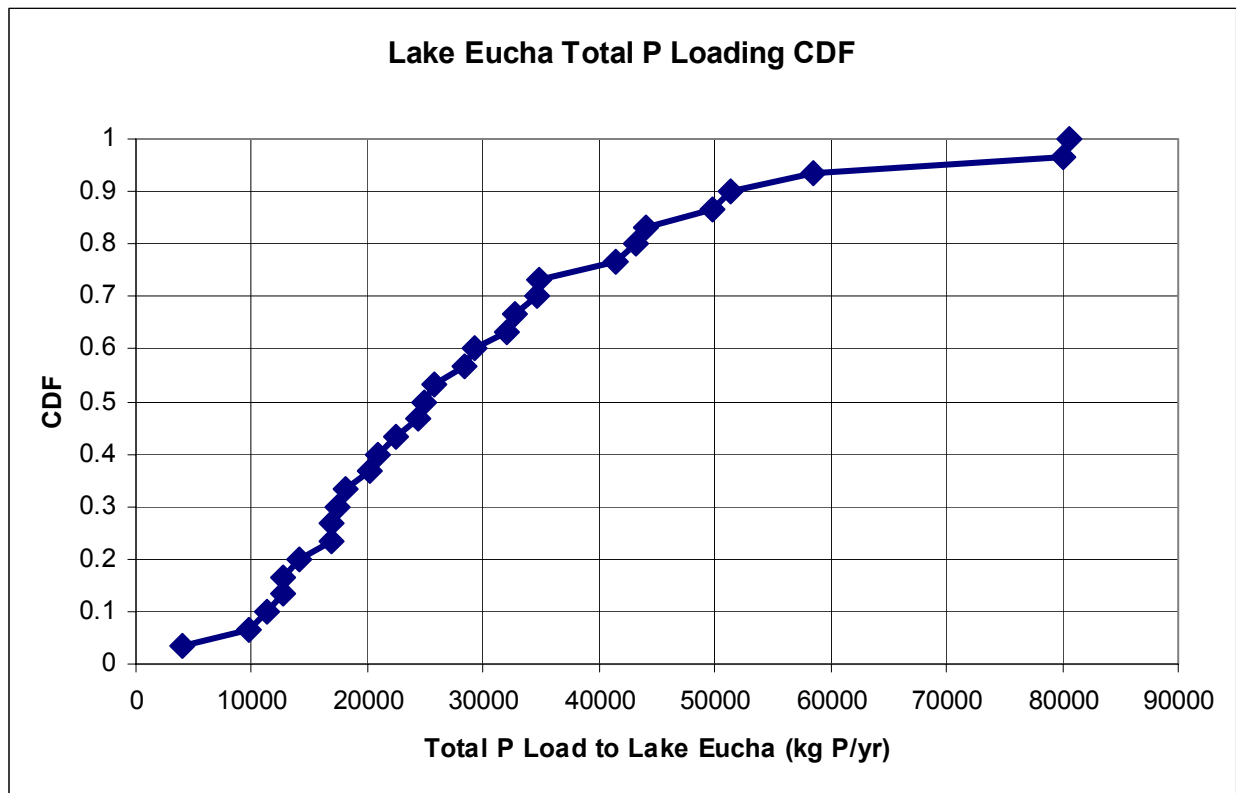


Figure 31 Cumulative Distribution Function (CDF) of nonpoint source total phosphorus loading to Lake Eucha under calibrated conditions as predicted by SWAT for the period 1970 to 1999. Derived from 30 simulations of the calibrated SWAT model.

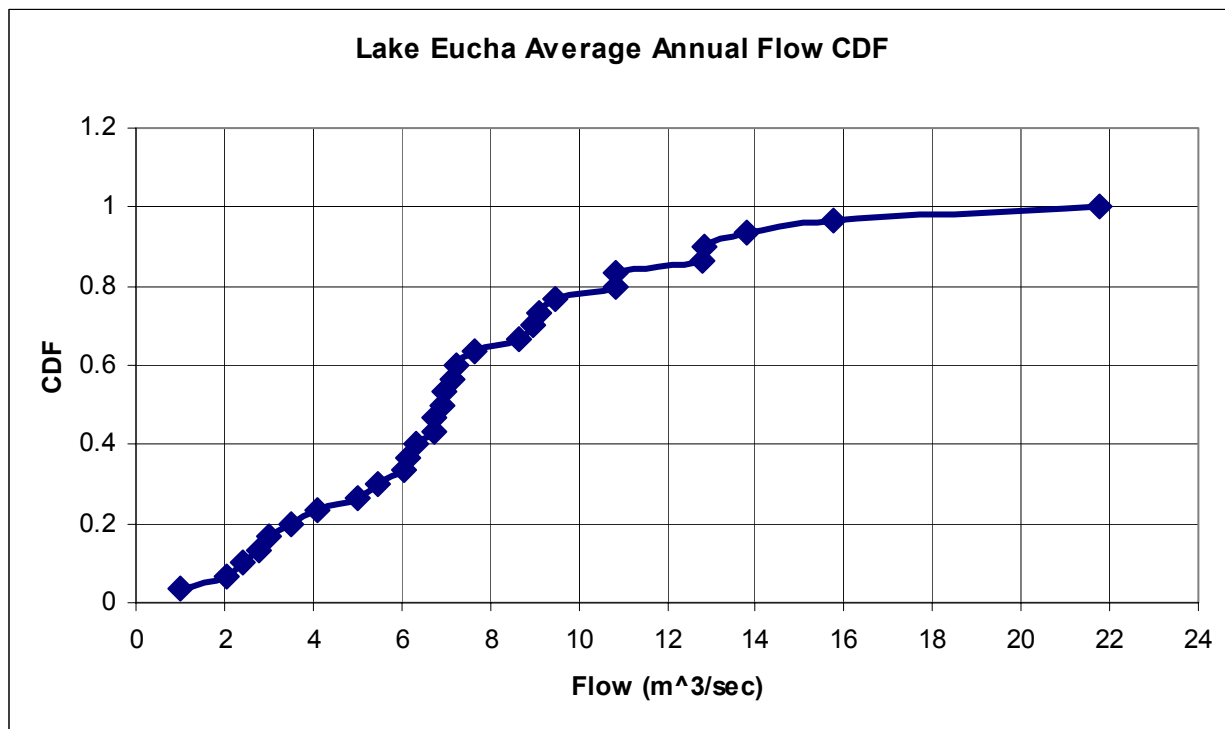


Figure 32 Cumulative Distribution Function (CDF) of predicted average annual streamflow to Lake Eucha derived from 30 simulations of the calibrated SWAT model for the period 1970 to 1999.

Table 20 Nonpoint source confidence intervals at calibrated conditions derived from 30 simulations from the calibrated SWAT model for the period 1970 to 1999.

Parameter	95%(High)	90%(High)	80%(High)	MEAN	80%(Low)	90%(Low)	95%(Low)
Flow (m ³ /sec)	23.41	19.04	14.98	7.74	2.79	2.19	1.78
Total P (kg/yr)	90,628	73,775	58,127	30,444	10,920	8,604	7,004
Soluble P (kg/yr)	22,339	18,442	14,769	7,973	3,110	2,491	2,056

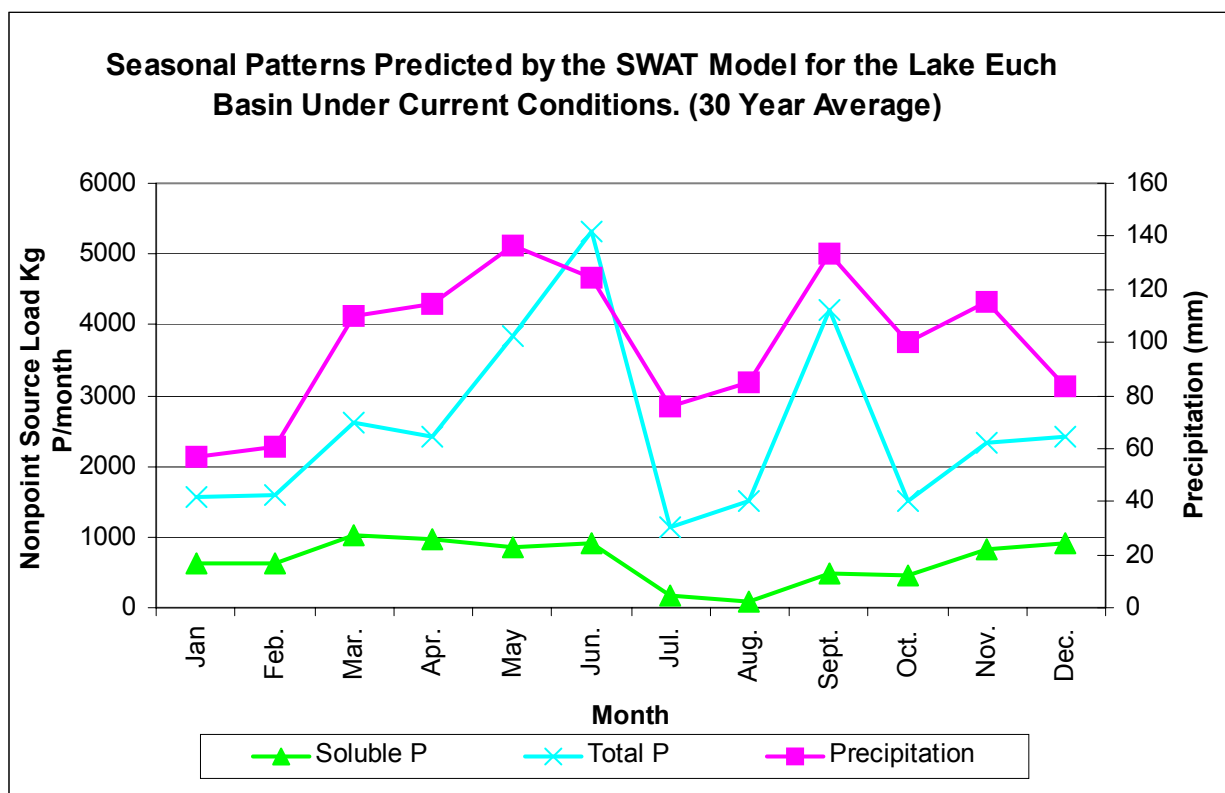


Figure 33 Seasonal Patterns predicted by the SWAT model for current conditions for the period 1970 to 1999.

Load Source Identification and Estimation

Using the SWAT model, a series of simulations were performed to determine the source of the current nutrient loading to Lake Eucha, both spatial (Figures 36a and 36b) and by management or land cover changes (Figure 34 and 34b). There are assumptions that must be made in addition to those made in the model to perform this type of analysis, and should be treated accordingly. These simulations span the period 1-98 to 12-2001. However, other time frames will yield similar results. The fraction of loading associated with each change to the model was isolated as follows:

- Load due to the application of poultry litter to pastures and row crop was estimated as the difference in the predicted load between the 1x application rate and the 0x rate.
- The contribution of STP was estimated as the difference between the calibrated model at current STP and 30 lb/acre STP scenarios.
- The effect of grazing was estimated as the difference between the model with grazing at the current rate and a model with a hay operations replacing cattle grazing.
- Loading due to land cover changes were estimated as the difference between (1) the current model with an STP of 30 and without cattle and litter and (2) an STP of 30 and all forested background conditions.

An additional term of STP/litter interaction was quantified by running the model with no litter and background STP and comparing this reduction to the sum of that attributed to both litter and STP. Interaction was surprisingly small (-1.5% for total P). Possibly because the prediction that STP increases have the largest effect on row crop, and litter application affects pastures to a greater extent. The effect of litter and STP may have some degree of spatial separation.

Loading by land cover was derived from the calibrated SWAT model. Row crop was estimated to contribute significantly more than previously thought, with 49% of the total load originating from only 2.6% of the basin (Figure 34a). It is important to note that this estimate assumes row crop has the same STP as pastures. Pastures only accounted for about 21% of the total P load, but accounted for 42% of the soluble P load. The distribution of soluble loading is very different (Figure 34b). These data are also available in Table 21.

The SWAT model also allows us to estimate not only the area from which the load originates, but also the activity or physical change in the basin that caused it. Figure 35 and Tables 22, 23 and 24 display these findings. It should be noted that the application of poultry litter over the past 40 years is also ultimately responsible for the current STP levels.

Because SWAT is a distributed model, we can map model results. Figure 36a and 36b indicate higher loading from the eastern portion of the basin, which is expected due to a higher STP, litter application, and greater fraction of pasture and row crop than the rest of the basin.

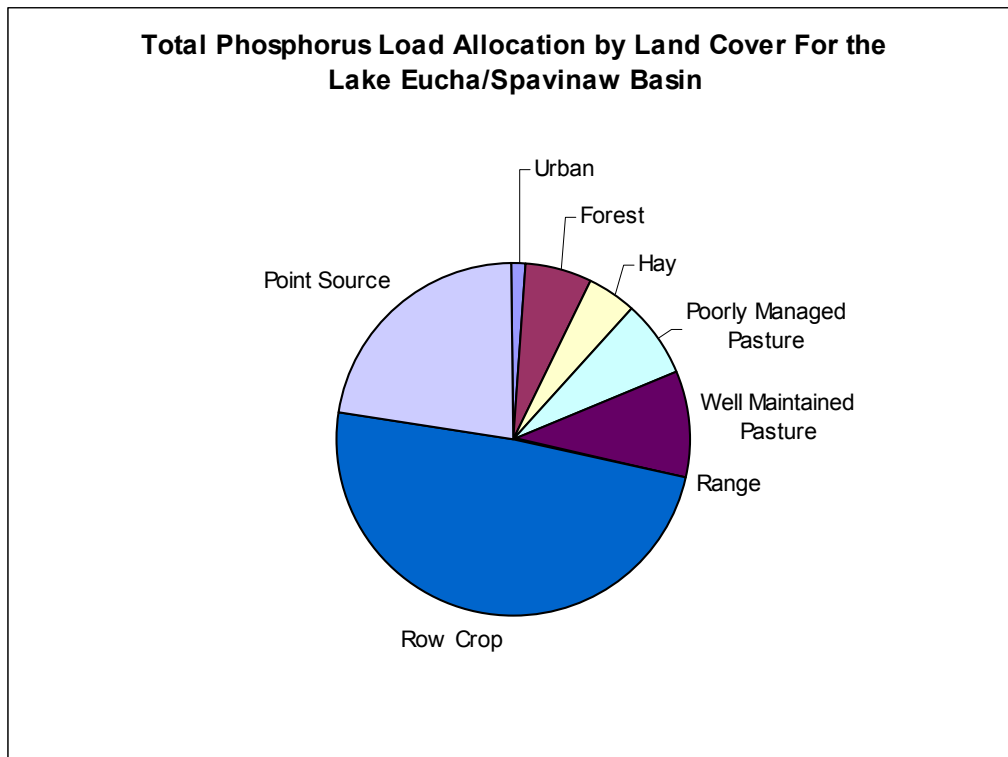


Figure 34a Total phosphorus load allocation by land cover for the Lake Eucha/Spavinaw basin. Derived from SWAT model predictions for the period 1/1998 to 12/2001.

Table 21 Total phosphorus load allocation by land cover for the Lake Eucha/Spavinaw basin. Derived from SWAT model predictions for the period 1/1998 to 12/2001.

Land Cover	Area (%)	Total P	Soluble P
Urban	1.3%	1.5%	1.1%
Forest	51.3%	6.1%	1.4%
Hay	13.3%	4.3%	9.8%
Poorly Managed Pasture	6.5%	6.9%	8.5%
Well Maintained Pasture	23.1%	9.8%	23.7%
Range	0.1%	0.0%	0.0%
Row Crop	2.6%	48.6%	3.7%
Point Source	NA	22.7%	51.8%

**Load Source (Soluble P Only) by Land Cover For the Lake
Eucha Basin**

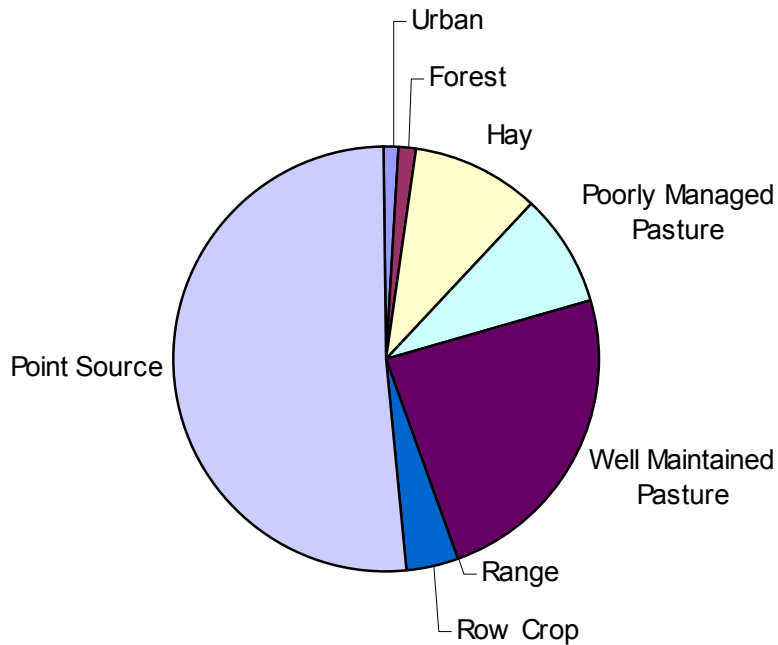


Figure 34b Load allocation of soluble phosphorus by land cover. Derived from SWAT model data for the period 1/1998 to 12/2001.

Table 22 SWAT predicted load by source for the Lake Eucha Basin by land cover.

Source	Total P			Soluble P		
	Total	Pastures	Rowcrop	Total	Pastures	Rowcrop
Due to litter	15.6%	46.6%	8.4%	27.2%	56.1%	13.6%
Due to STP	38.6%	17.8%	70.4%	11.3%	16.4%	86.8%
Due to STP litter interaction	-1.5%	-1.0%	-2.5%	-1.6%	-3.2%	-3.3%
Due to land cover change	11.7%	9.8%	23.1%	1.6%	13.5%	0.2%
Due to grazing	4.2%	16.5%	0.3%	7.2%	15.0%	1.2%
Background conditions	8.7%	10.4%	0.3%	2.6%	2.2%	1.6%
Decatur point source	22.7%	N/A	N/A	51.8%	N/A	N/A

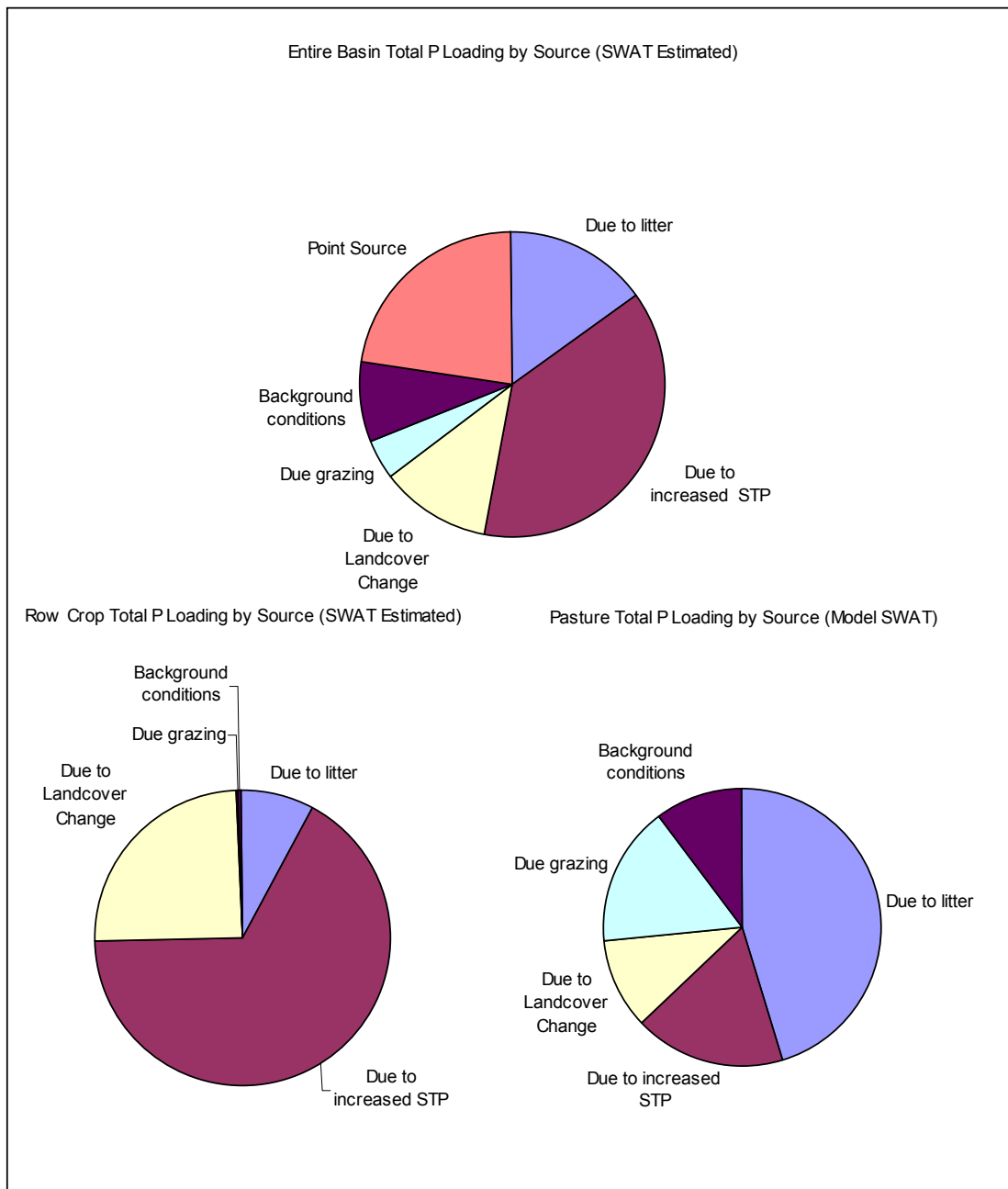


Figure 35 Total phosphorus load by source for the Lake Eucha/Spavinaw basin and for pasture and row crop. Derived from SWAT model data for the period 1/1998 to 12/2001. STP/litter interaction is distributed across litter and STP.

Table 23 Phosphorus load by land cover for several scenarios. Derived from SWAT model prediction for the period 1/1998 to 12/2001.

Scenario	Urban Forest	Hay	Poorly Managed Pasture	Range	Well Maintained Pasture	Row Crop	Basin Total	All Pastures	Row Crop	
Total P Kg/yr										
Calibrated	773	3,085	2,195	3,502	25	4,968	24,677	39,223	10,665	24,677
No Litter	773	3,085	510	2,280	25	2,000	22,650	31,322	4,789	22,650
Low STP	439	3,085	1,694	2,539	25	4,183	7,678	19,643	8,416	7,678
Low STP No Litter	439	3,085	194	1,187	25	1,292	6,265	12,487	2,673	6,265
Low STP no Litter no Cattle	439	3,085	194	113	25	289	6,193	10,338	596	6,193
Point Source								11,530		
Background	71	2,964	378	199	4	732	67	4,416	1,310	67
Soluble P Kg/yr										
Calibrated	216	285	1,963	1,704	3	4,727	729	9,628	8,395	729
No Litter	216	285	406	794	3	1,857	632	4,193	3,057	632
Low STP	143	285	1,527	1,316	3	3,993	109	7,377	6,836	109
Low STP No Litter	143	285	130	472	3	1,201	36	2,270	1,803	36
Low STP no Litter no Cattle	143	285	130	78	3	170	27	837	378	27
Point Source 90% Sol								10,337		
Background	16	276	61	28	1	121	11	515	210	11

Table 24 Phosphorus load source by land cover for the Lake Eucha/Spavinaw basin. Derived from SWAT model predictions for the period 1/1998 to 12/2001. Assumes point source is 90 percent soluble P.

Load Source	Total P Kg/yr			Soluble P Kg/yr		
	Basin	Pastures	Row Crop	Basin	Pastures	Row Crop
Due to litter	7,902	5,875	2,027	5,435	5,338	97
Due to STP	19,580	2,248	16,999	2,251	1,559	619
Litter STP Interaction	-746	-132	-614	-328	-305	-23
Due to Grazing	2,149	2,077	72	1,433	1,425	9
Due to Landcover	5,922	1,231	5,584	322	1,288	1
Background Conditions	4,416	1,310	67	515	210	11
NPS total	39,223	12,609	24,135	9,628	9,515	714
Point Source	11,530			10,337		
Total	50,753	12,609	24,135	19,965	9,515	714

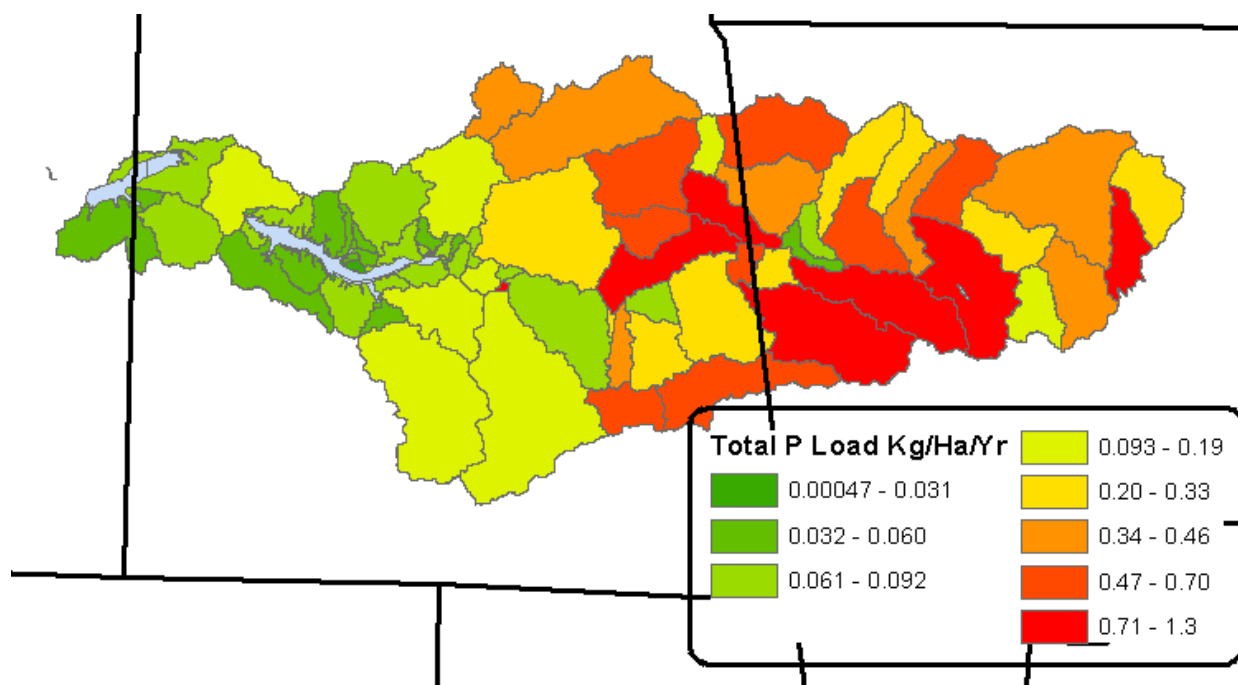


Figure 36a SWAT predicted spatial distribution of total P load per unit area for the Lake Eucha/Spavinaw basin at current conditions.

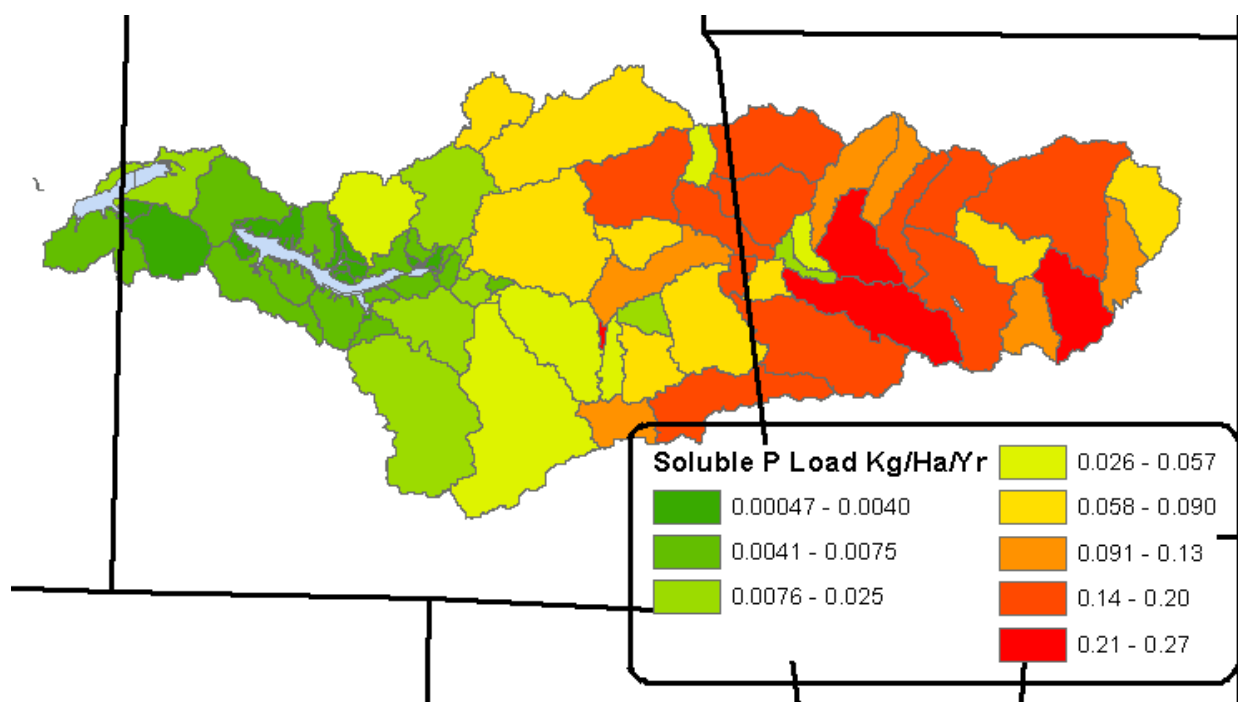


Figure 36b SWAT predicted spatial distribution of soluble P load per unit area for the Lake Eucha/Spavinaw basin at current conditions.

Management Practice Simulations

The calibrated model was modified to simulate a variety of BMPs and management practices. Litter application rate and STP were modified. Each scenario is evaluated using the method detailed in the previous section.

Poultry Litter Application Scenarios

Poultry litter was assumed to be applied only to pastures and row crop, and the application rate varies by subbasin. The amount of poultry litter applied in each subbasin was assumed to be equal to the estimated litter production in that subbasin. Poultry litter application rates from 0 to 1.5 times the current rate were modeled. The current average litter application rate to pasture and row crop for the entire basin is 0.81 t/acre and the average for subbasins containing poultry houses is 0.99 t/acre. These rates are average annual application rates and assume all pasture and row crop fields receive litter. These rates should not be confused with the rate at which litter is generally applied to a particular field. Some pastures will not receive litter at all, and others will receive litter every year. Commercial nitrogen was supplemented at litter application rates less than the current rate to maintain the current total nitrogen rate and forage production. The model simulated a positive correlation between poultry litter application rate and phosphorus loading (Figures 37, 38, and Table 25). Poultry litter application rates primarily affect nutrients, but do have some effect on the hydrology. Poultry litter applications influence plant growth which in turn effects surface residue and evapotranspiration. It should be noted, that SWAT does not directly simulate the surface application of litter; it is treated an addition of nutrients to the surface soil layer.

Soil Test Phosphorus Scenarios

To determine the relationship between STP and phosphorus loading, an additional set of model runs was made. The STP for all pastures and row crop was set to a single value across the basin and varied, but forest STP was not modified. To single out the effect of STP, no poultry litter was applied in one set of these simulations (Figure 40). An additional set was performed that did include poultry litter application at the current-estimated rate (Figure 39 and 41). These data are also available in Table 26.

Soil test phosphorus mainly affects soluble and sediment-bound phosphorus loadings. STP has little effect on flow. Plant growth depends on the poultry litter as a source of nitrogen; without it there is significantly less growth and residue. With reduced residue and plant growth the soil surface is more exposed and subject to additional soil erosion. All simulations in this report at reduced poultry litter application rates use enough supplemental commercial nitrogen to maintain the current total nitrogen application rate.

City of Decatur Point Source Control

We disabled the SWAT in-stream process and thus the City of Decatur point source was not included in the modeling. With the in-stream process disabled, any included point source would simply be additive to the load downstream. It is more convenient to simply add the point source outside the SWAT model. The observed total annual phosphorus point source loading is estimated to be 11,360 kg/year. The discharge from the plant has an estimated average concentration of 6.55 mg P/l. Table 27 displays the load at differing average concentration.

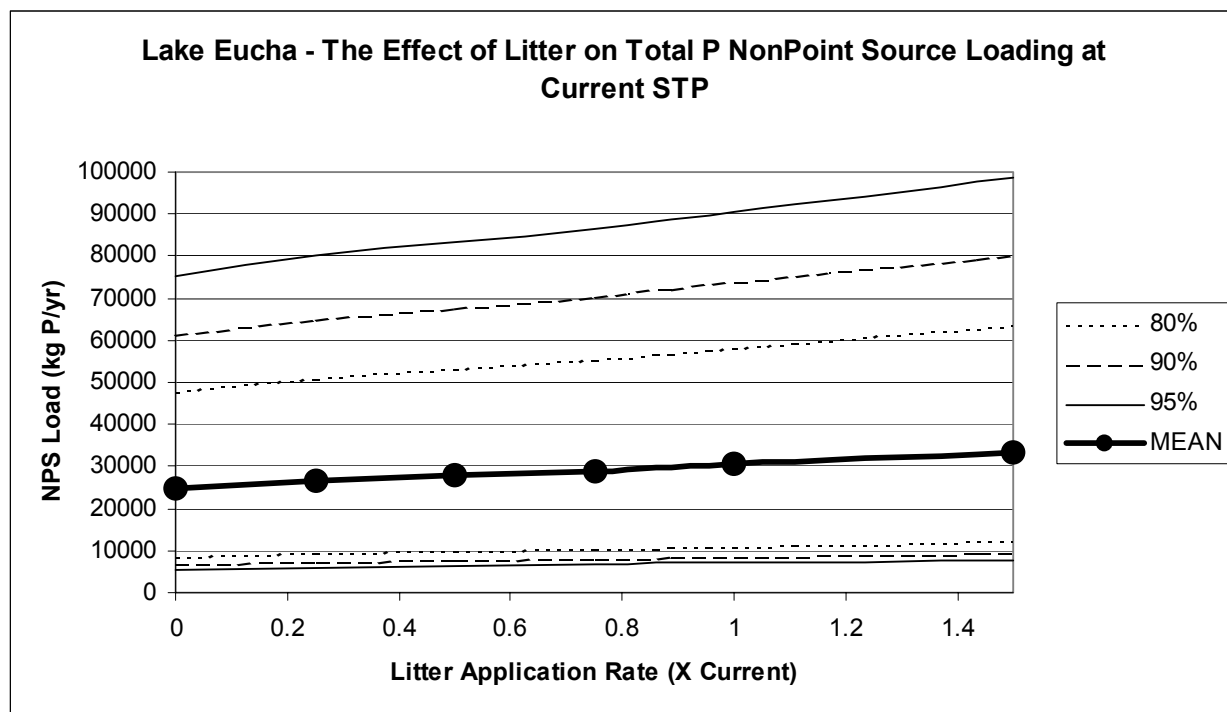


Figure 37 SWAT simulated nonpoint source total phosphorus load to Lake Eucha as a function of current poultry litter application rate at current soil test phosphorus levels. Confidence intervals based on 30 year weather SWAT simulation for the period 1970 to 1999.

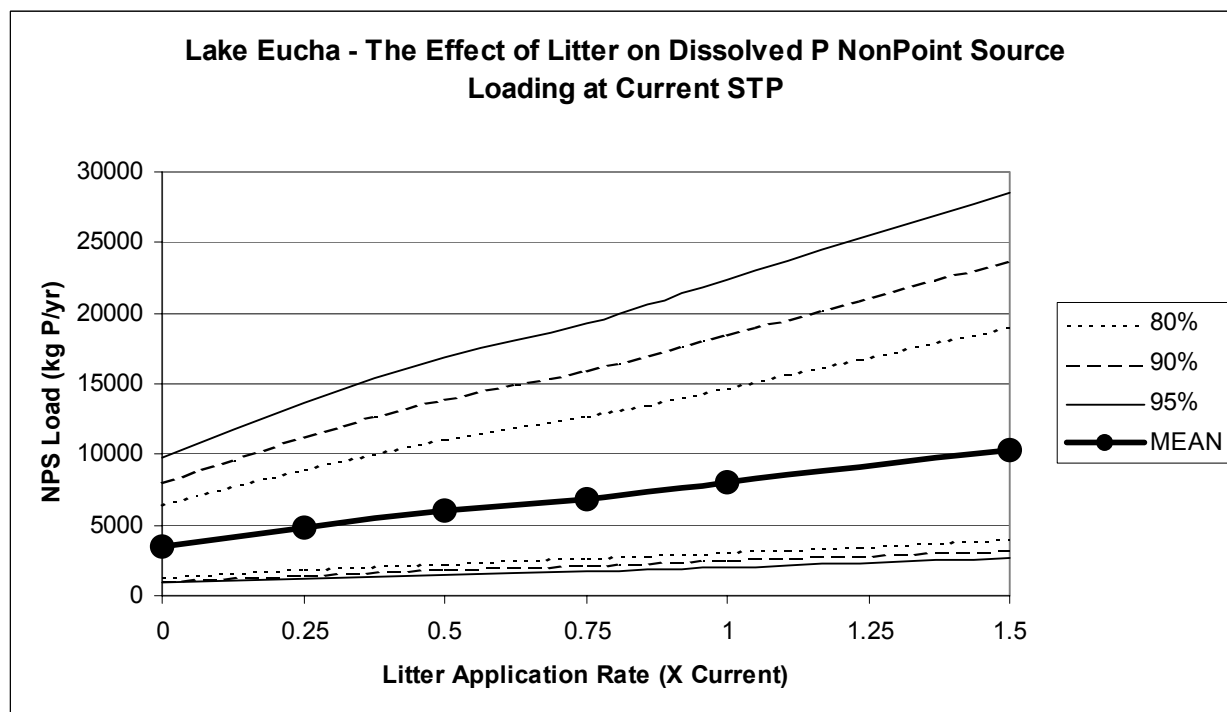


Figure 38 SWAT simulated nonpoint source soluble phosphorus load to Lake Eucha as a function of poultry litter application rate at current soil test phosphorus levels. Confidence intervals based on 30 year weather SWAT simulation for the period 1970 to 1999.

Table 25 SWAT simulated effect of current poultry litter applications rate on nonpoint source load to Lake Eucha. Confidence intervals based on 30 year weather SWAT simulation for the period 1970 to 1999.

Litter Application Rate (X Current)	CI	Total P (kg/yr)	Soluble P (kg/yr)
0	95% (High)	75,296	9,749
0	90% (high)	61,099	8,037
0	80% (High)	47,962	6,425
0	MEAN	24,909	3,433
0	80% (Low)	8,780	1,337
0	90% (Low)	6,892	1,069
0	95% (Low)	5,592	881
0.25	95% (High)	79,958	13,679
0.25	90% (high)	64,958	11,280
0.25	80% (High)	51,059	9,022
0.25	MEAN	26,592	4,839
0.25	80% (Low)	9,435	1,883
0.25	90% (Low)	7,416	1,506
0.25	95% (Low)	6,025	1,242
0.5	95% (High)	83,302	16,855
0.5	90% (high)	67,739	13,896
0.5	80% (High)	53,305	11,110
0.5	MEAN	27,830	5,963
0.5	80% (Low)	9,928	2,313
0.5	90% (Low)	7,812	1,849
0.5	95% (Low)	6,353	1,525
0.75	95% (High)	86,584	19,344
0.75	90% (high)	70,425	15,958
0.75	80% (High)	55,435	12,768
0.75	MEAN	28,966	6,874
0.75	80% (Low)	10,345	2,673
0.75	90% (Low)	8,143	2,139
0.75	95% (Low)	6,623	1,764
1.0	95% (High)	90,628	22,339
1.0	90% (high)	73,775	18,442
1.0	80% (High)	58,127	14,769
1.0	MEAN	30,444	7,973
1.0	80% (Low)	10,920	3,110
1.0	90% (Low)	8,604	2,491
1.0	95% (Low)	7,004	2,056
1.5	95% (High)	98,449	28,593
1.5	90% (high)	80,263	23,660
1.5	80% (High)	63,349	18,999
1.5	MEAN	33,319	10,331
1.5	80% (Low)	12,048	4,077
1.5	90% (Low)	9,509	3,274
1.5	95% (Low)	7,753	2,709

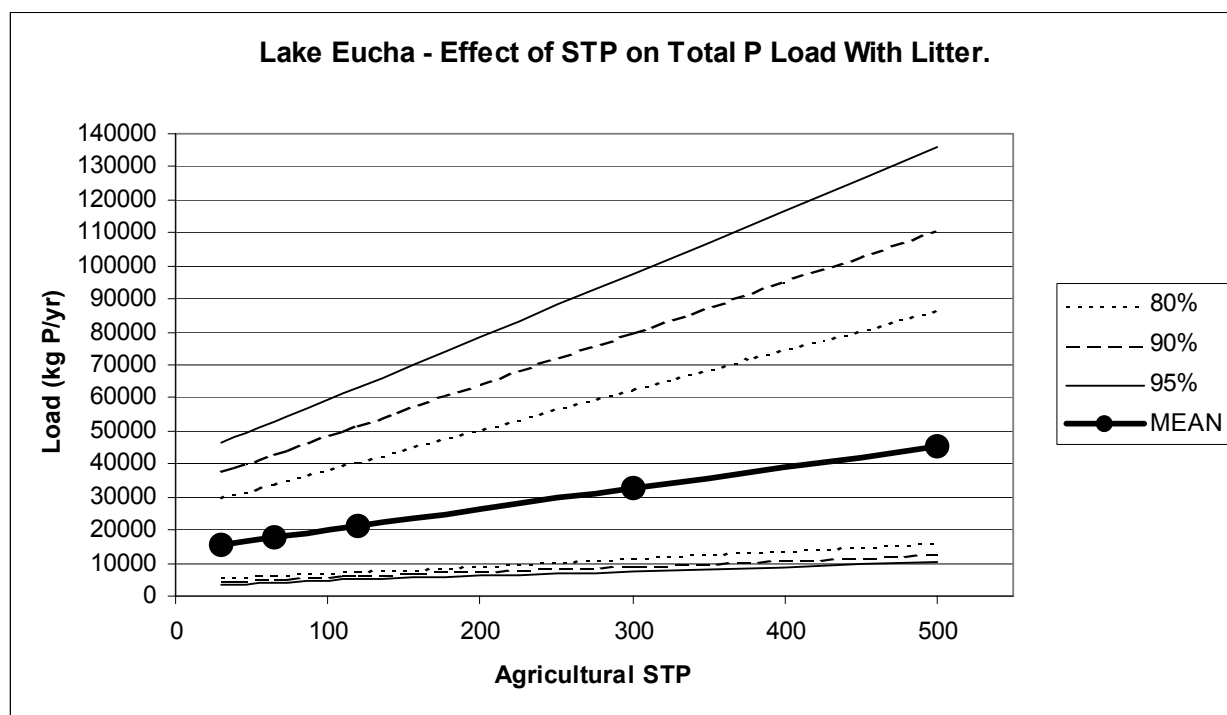


Figure 39 Effect of agricultural (pasture and row crop) soil test phosphorus (STP) on total nonpoint source phosphorus loading to Lake Eucha as simulated by SWAT using the current poultry litter application rate for the period 1970 to 1999.

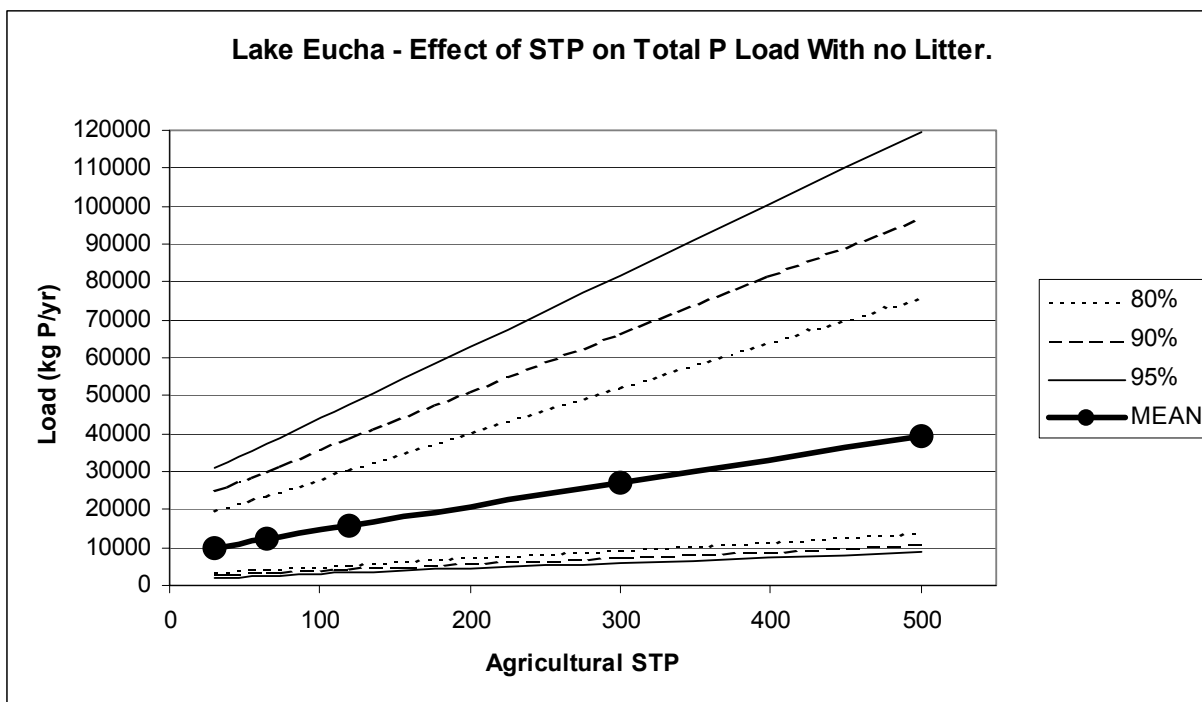


Figure 40 SWAT simulated Total phosphorus nonpoint source loading to Lake Eucha as a function of agricultural (pasture and row crop) soil test phosphorus (STP) for the period 1970 to 1999. No applied poultry litter and commercial nitrogen application is equivalent to current poultry litter application rate.

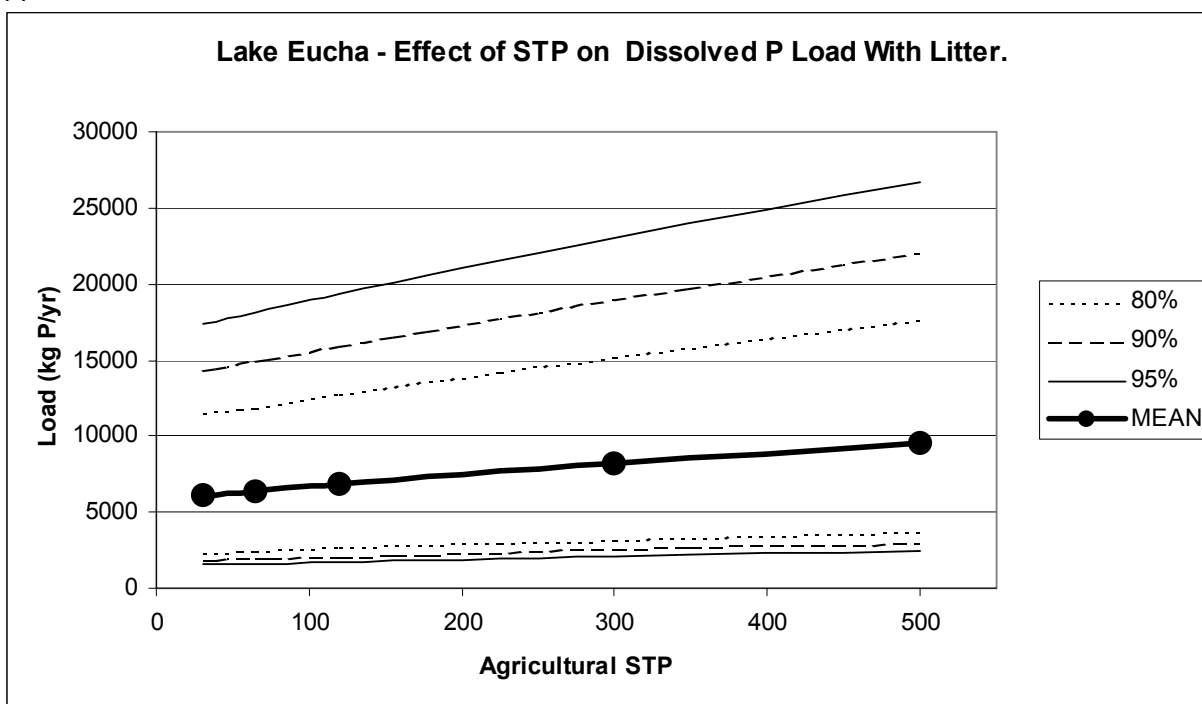


Figure 41 Total phosphorus nonpoint source loading to Lake Eucha as a function of agricultural (pasture and row crop) soil test phosphorus (STP) as simulated by SWAT using the current litter rate for the period 1970 to 1999.

Table 26 SWAT simulated effect of Soil Test Phosphorus (STP) on nonpoint source load to Lake Eucha. Confidence intervals based on 30 year weather SWAT simulation for the period 1970 to 1999. Simulations without the application of poultry litter add commercial nitrogen application is equivalent to current poultry litter application rate. (kg P/yr)

STP	CI	With Litter		No Litter	
		Soluble P	Total P	Soluble P	Total P
30	95% (High)	17,407	46,248	5,514	30,829
30	90% (high)	14,339	37,741	4,507	24,935
30	80% (High)	11,454	29,821	3,568	19,500
30	MEAN	6,147	15,664	1,856	9,985
30	80% (Low)	2,370	5,716	693	3,476
30	90% (Low)	1,893	4,517	548	2,719
30	95% (Low)	1,559	3,686	448	2,199
65	95% (High)	18,091	52,667	6,173	37,153
65	90% (high)	14,914	42,984	5,049	30,095
65	80% (High)	11,924	33,967	4,001	23,577
65	MEAN	6,414	17,860	2,087	12,141
65	80% (Low)	2,482	6,516	782	4,255
65	90% (Low)	1,984	5,149	619	3,333
65	95% (Low)	1,636	4,202	507	2,700
120	95% (High)	19,299	63,171	7,337	47,723
120	90% (high)	15,913	51,507	5,999	38,644
120	80% (High)	12,725	40,659	4,751	30,262
120	MEAN	6,847	21,335	2,475	15,582
120	80% (Low)	2,653	7,740	925	5,447
120	90% (Low)	2,121	6,109	733	4,266
120	95% (Low)	1,749	4,981	599	3,454
300	95% (High)	23,037	97,728	10,275	81,641
300	90% (high)	18,997	79,497	8,466	66,179
300	80% (High)	15,194	62,582	6,764	51,887
300	MEAN	8,175	32,698	3,611	26,859
300	80% (Low)	3,171	11,688	1,401	9,418
300	90% (Low)	2,536	9,201	1,120	7,384
300	95% (Low)	2,092	7,485	922	5,986
500	95% (High)	26,742	136,181	13,443	119,508
500	90% (high)	22,077	110,602	11,091	96,861
500	80% (High)	17,680	86,909	8,875	75,930
500	MEAN	9,542	45,281	4,758	39,338
500	80% (Low)	3,723	16,024	1,859	13,767
500	90% (Low)	2,982	12,591	1,488	10,792
500	95% (Low)	2,462	10,226	1,227	8,747

Table 27 Nutrient loading for the City of Decatur point source at varying effluent concentrations. Shaded concentration and load is estimated from Permit Compliance System data from the US Environmental Protection Agency for the period Jan 98 to March 2002. (Assumes constant flow rate)

Concentration (mg P/l)	Loading kg P/yr)
8	13,876
6.55	11,361
5	8,672
4	6,938
3	5,203
2	3,469
1	1,734
0.5	867
0.25	434

Study and Model Limitations

There are several limitations that should be noted. Limitations may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is not perfect nor complete, and a model by definition is a simplification of the real world. Understanding the limitations helps assure that accurate inferences are drawn from model predictions.

Weather is the driving force for any hydrologic model and thus uncertainty in the rainfall or the rainfall distribution across the watershed is important. Great care was, therefore, taken to include as much accurate, observed weather data as possible. The inclusion of NEXRAD derived weather data should in theory, improve the accuracy of the model and reduce this limitation. However this was not evaluated in this study. Rainfall is estimated on a 4 km grid. Rainfall can be quite variable even within a single grid cell, especially in the spring and summer when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at one location, but be dry a short distance away. On an average annual or average monthly basis, these errors have less influence since they are typically not additive. This limitation, among others, cautions us against using model output on a daily basis.

The assumption that STP for row crop is similar to that of pastures is of critical importance as the phosphorous loading from row crop is proportional to STP. Data are currently not available to verify the actual row crop STP. Additional soil sampling in these areas should be conducted in future studies. The high phosphorus loading rate shown for row crop is largely the result of erosion, as erosion rates for conventional tillage row crops are typically at least an order of magnitude higher than pasture. Additional field-scale and/or watershed-scale monitoring would help validate the contribution from row crop.

The SWAT model assumes total phosphorus includes labile, active, and stable forms in a fixed ratio. Phosphorus loading from pasture originates primarily from labile forms of soil phosphorus due to low erosion. Phosphorus loading from row crops, where erosion is high, contains all forms of soil phosphorus including labile, active and stable forms. The SWAT model calculates stable

mineral phosphorus based on active and labile phosphorus. We assume that Mehlich III soil test is equal to the sum of the labile and active mineral forms, which is model input. The ratio of active to stable forms at equilibrium is set via a single basin-wide model input in SWAT. The equilibrium ratio of active and stable forms is fixed in SWAT, although both ratios probably vary with soil type. This assumption governs the relative loading from pasture and row crop. Therefore, if active and stable phosphorus forms are over estimated the relative contribution of phosphorus from row crop will be over predicted.

Scenarios involving radical departures from calibration conditions result in greater uncertainty. Although calibration assures the user that the results reflect the range of conditions encountered at the watershed, they do not assure the model will be accurate for drastic changes in land use or management.

Only a single point source was included in this analysis, although there are many other minor sources in the basin. These other sources, such as CAFOs, septic tanks and small communities, were considered negligible.

There is uncertainty associated with specifying uniform management for a land cover category. It is not practical to specify management for every field in the basin, and thus a typical management was selected and applied basin-wide for each land cover type. Management operations include grazing, fertilization, tillage, planting, and harvesting.

An important limitation is that SWAT simulates poultry litter applications as simple nutrient additions applied uniformly to the top 10 mm of the soil surface. In reality poultry litter lies on the soil surface until rainfall moves it into the soil. In the first few rainfall events after application the litter may interact more closely with surface runoff than simulated by SWAT. In the field we would expect high phosphorus concentrations in surface runoff when rainfall occurs immediately following litter application, but lower concentrations later in the season. In the SWAT model, high short term phosphorus concentrations may not be simulated, but through calibration accuracy is achieved for monthly and annual phosphorus loads. This limitation makes it inadvisable to use daily simulation results.

Conclusions

Several important conclusions may be drawn from this study. It should be noted, however, that these conclusions are derived from SWAT model predictions and observed water quality data and thus are subject to the same limitations and context.

- Simulation suggests that row crop contributes 49% of the total phosphorus loading while covering only 2.6% of the basin. Additional studies are needed to confirm this prediction.
- The City of Decatur point source accounts for 23% of the total phosphorous load to Lake Eucha.
- The SWAT model suggests that the majority of nonpoint source total phosphorus loading is due to the elevated soil test phosphorus from row crop fields, but the majority of soluble phosphorus is due to the application of poultry litter to pastures.
- SWAT suggests the cessation of poultry litter application will reduce total phosphorus loads

by 16% and soluble phosphorus loads by 27%.

- Loading per unit area is higher in the eastern portion of the basin.

One of the most significant findings of this study is the contribution of total phosphorus loading to Lake Eucha from row crop fields. The contribution from row crop is disproportionately high relative to pasture. Our assumptions of STP, and phosphorus and erosion parameters for the row crop fields are key to our estimate and should be verified in future studies. The reduction in phosphorus loads from row crop fields will require the implementation of erosion control BMPs or conversion to pasture. Changing row crop to pastures would, according to the SWAT model, reduce total phosphorus loads by almost 50%.

An additional finding is the dramatic difference in the sources of total and soluble phosphorus. Plans to control phosphorus loads to Lakes Eucha and Spavinaw may need to consider phosphorus bioavailability. The SWAT model suggest that soluble phosphorus, i.e. highly bioavailable phosphorus, comes from the application of poultry litter to pastures in the basin, as well as the City of Decatur point source. Reduced application of poultry litter to pastures and reduction of the point source could dramatically reduce the soluble P loading in a relatively short time frame.

Phosphorus loading per unit area is correlated to STP and litter application rate. For this reason the SWAT model estimates higher phosphorus load per unit area from the eastern portion of the basin, which has higher density of poultry houses, higher average STP, and more row crop production.

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